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Controlling Game Music in Real Time with Biosignals

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Controlling Game Music in Real Time with Biosignals

by

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Report

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Abstract

Controlling Game Music in Real Time with Biosignals

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Effective game music is typically adaptive, interactive, or both. Changes in game music are usually influenced by the current state of the game or the actions of the player. To provide another dimension of interactivity, it would be useful to know the affective state of the human player. Biosignals are continuous signals generated by a person that can be measured over time, and have been shown to reflect affective state. This project demonstrates that control signals can be gathered from the player and mapped to musical parameters. Using a heart rate sensor and galvanic skin response sensor built from open source designs, we have used biosignals to control music playback while playing four games from different genres.

A system for controlling game music with biosignals is computationally cheap, and can provide data that is useful to other game systems. The prototype developed for this project is basic, but with further research and development, we believe such a system will greatly improve the immersive experience of video games by involving the player on a new level.

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Chapter 1: Introduction

Music is an essential part of the game experience. The effect of music in a game goes beyond the role of highlighting events or suggesting moods as in linear media. Music in games may also function as a messenger, cueing the player to prepare for action or alerting the player to hurry up. Game music is free of the timeline, it can be both adaptive and interactive, cueing and responding to the player. However, this communication between player and game system is still limited. A biofeedback system that is built on the principles of affective computing can augment that communication, making the experience more unique and immersive (Collins 2008).

The relatively new field of affective computing exposes new methods to access, analyze, and reflect emotional responses in human-computer interactions. Over the years, occasional attempts have been made by the gaming industry to incorporate novel methods of biosignal input to games. More recently, researchers and game enthusiasts have taken advantage of the availability of low cost microcontrollers and biosensors to build prototypes and experiment with new modes of interaction. Video games provide an ideal platform to begin developing and implementing simple affective computing techniques using biosignals.

The purpose of this project is to present a prototype design of a system for controlling game music with biosignals measured and processed during game play. The design should reinforce the affective state of the player by changing the music intensity level accordingly. The process will demonstrate that a low cost system can be built that is effective and simple to work with. The choice to design such a system is motivated by the desire to show that game music can be more dynamic using a novel input signal for playback parameter control. Hopefully, the lessons learned in the process will also inform other areas of game design and provide another tool for the game designer to create more responsive environments.

Chapter 2: Background

Affective Computing

In human communication, most emotions manifest physically in ways that provide clues about a person's inner state in what is known as sentic modulation. Observing sentic modulations is one way to recognize affective states. Humans have developed the ability to recognize affective states from sentic modulations, even across cultural boundaries, but this is a much more difficult task for machines (Zeng et al. 2009). Most human-computer interactions require the user to adopt a mode of communication best suited to the computer system, with the result that the data from sentic modulations found in human communication is lost or ignored. The spread of interactive computing environments will require a shift from the current model of computer-centered design to human-centered design for human-computer interactions. Better tools for human affect perception must be developed in order to produce this shift.

Affective computing is computing that relates to, arises from, or deliberately influences emotion or other affective phenomena. This field encompasses several disciplines including psychology, linguistics, computer vision, speech analysis, and machine learning (MIT 2012). Affective computing begins with establishing methods for representing the parts of an affective system as different levels. At the lowest level are affective signals; detectable changes that carry information. These signals combine to create patterns of emotional displays. Emotions are then represented as concepts at the highest level (Picard 1997). For a machine to recognize affect, first the low level signals must be detected. Sensors may detect physiological cues the same as humans do, or directly capture affective signals to gather the data necessary for extracting meaningful patterns (Westland 2011). In order to identify the concepts represented by those patterns, contextual signals from the environment must be combined with the patterns derived from affective signals (Picard 1997).

An affective state is not discrete and cannot be directly observed, so representations of emotions must be established. Emotional theory describes several models for representing emotions, and understanding each model can help in developing tools for affective recognition (Picard 1997, Zeng et al. 2009). The "basic emotions" model separates emotions in to discrete categories of happiness, fear, disgust, sadness, anger, and surprise. This model is intuitive for humans, but not as simple for computers to recognize. It also does not reflect the wide range of emotions found in communication. The "dimensional" model characterizes affective states in terms of latent dimensions including valence, control, activation, and power. The main aspects of emotion are reflected in the valence and activation dimensions. Valence describes a range of positive to negative, while activation describes engagement or arousal, from active to passive. This model allows for a description of a range of affect, but much information is lost. Descriptions of emotions become oversimplified when projecting complex states on two dimensions. Fear and anger become indistinguishable for example. This model is not intuitive and requires training to apply. The newest model in emotion theory is the "appraisal-based" approach, which describes emotion through a set of stimulus evaluation checks. This includes novelty, intrinsic pleasantness, goal based significance, coping potential, and compatibility with standards. This model is much less intuitive than previous models and more challenging to apply to automatic emotion recognition systems (Zeng et al. 2009). Determining affective states works best when attempting to recognize the broad dimensions of emotion. The basic or prototype emotions are too nuanced to derive directly from measuring affective signals, but it is helpful to distinguish between primary and secondary emotions when choosing which affective signals to measure. Primary emotions result from visceral arousal, while secondary emotions arise from cognitive evaluation of a situation (Picard 1995).

An affective signal is a continuous physiological data stream that changes over time. Some affective signals require special equipment to be observed, while for others, eyes, ears, and hands work nicely. Depending on the intensity and type of emotion, as well as the individual, an affective signal can appear in behavior as the voice, face, eyes, grip, or gait transmit sentic modulations. Humans can interpret these cues in the appropriate context, but below the surface of awareness, there is another type of affective signal, the biosignal, which requires more specialized techniques to measure.

BIOSIGNALS

Heart rate, respiration, galvanic skin response, electrical brain activity, and skin temperature are some of the ways in which emotional expression is highlighted. Most of these biosignals can be detected without special sensors, but when measured and analyzed with the proper equipment, they can expose even more information about a person's affective state than is evident through regular human contact. I use the term biosignal to describe an affective signal that is expressed unconsciously, such as the changes in skin moisture that are part of the galvanic skin response. Other biosignals can be detected only with the proper equipment, such as electrical brain activity. In order to exploit all of these biosignals for entertainment or telecommunication applications, sensors and a computer interface are necessary for proper measurement and analysis.

Biometrics

It is important to distinguish biosignals from biometrics. A biometric is a static measurement of a physiological feature or behavioral characteristic used for identification or verification of identity. Examples of biometric identifiers include fingerprints, DNA, voice spectrum, and signature geometry (Schneier 1999). The distinction between biometrics and biosignals can be seen in the application as well. The use of biometrics requires an enrollment process in which biometric data is submitted and stored for later comparison. Biosignals and most affective data however, can be acquired and analyzed in real time. Comparison to generic affective data examples stored in a database has been implemented in some affective computing systems, but is not a key feature of most systems strictly using biosignals. Collecting and using affective data streams has raised some privacy concerns, much the same as those raised with the use and storage of biometric data. These concerns are valid, but that discussion is beyond the scope of this report (NYU 2012).

Galvanic Skin Response

As the name indicates, the galvanic skin response (GSR) is not an electrical signal given off by the body. It refers to a change in the electrical properties of skin as a response to stimuli. One does not need any special equipment to observe the phenomenon indirectly; sometimes just a handshake will suffice. However, in order to quantify, measure, and record this biosignal, an electric current must be applied to the skin. Using a very low voltage direct current (DC) and a circuit designed to measure an unknown electrical resistance, this biosignal and its complex relationship to emotions may be exploited for a number of applications.

The galvanic skin response is a result of the workings of the autonomic nervous system. Part of the peripheral nervous system, the autonomic nervous system functions largely below the level of consciousness, handling the visceral or involuntary functions of the body. This includes the sympathetic nervous system and parasympathetic nervous system. The former handles fight-or-flight reactions, mobilizing the body's resources under stress, while the latter handles rest-and-digest functions (Biomedical Signal Analysis Group 2012).

The galvanic skin response is a fight-or-flight reaction. As a response to stress, the sympathetic nervous system stimulates metabolic output to deal with external challenges by redirecting blood from digestion to muscles, heart, brain, and lungs in preparation for motor action. An auditory or visual surprise, pain, or other attention-grabbing stimuli can trigger this response. Outward signs of the sympathetic nervous system in action include increased respiration, heart rate, blood pressure, skin temperature, and sweat production (Poh et al. 2010).

The most common sweat gland on the human body is the eccrine gland. Sweat from these glands has three functions depending on its location. Activation sweat is produced on the palmar sides of the hands and soles of the feet where the concentration of eccrine sweat glands is greatest, more than $2000/cm^2$ (Kappeler-Setz et al. 2011). This helps protect these important surfaces while the body is in fight-or-flight mode and also improves grip. Thermoregulation sweat helps manage body temperature while also handling excretion and is produced over the rest of the body. To make its way to the surface of the skin, sweat must pass through the stratum corneum, which is the layer of dead skin cells that helps protect the tissue layers beneath. This layer is made primarily of keratin, a protein that prevents water evaporation from the dermis. It is thickest on the palmar region of the hands and soles of the feet with roughly twelve to twenty layers measuring 10-40 μm. The stratum corneum can absorb water and is perforated by sweat ducts that secrete glycogen, water, and electrolytes. Muscle cells that can contract quickly and expel sweat in hundredths of a second surround these ducts.

Measuring the changes in the electrical properties of the skin caused by sweat is a simple, reproducible method of capturing autonomic nerve response as a parameter of sweat gland function and pore size. Sweat is roughly 2.0-3.8% sodium, about the same as seawater, making it a suitable conductor. The stratum corneum absorbs the salt water in sweat as a hydrogen-bonded network of water molecules, forming a protonic semiconductor. As sweat is produced and pores open and close, the electrical resistance of the skin changes. To measure this change, electrodes are placed on the skin, usually on the palmar regions, as part of a circuit that measures electrical resistance or conductance. Conductance is the inverse of resistance, so it is not unusual to see galvanic skin response measurements in either ohms (Ω,) the unit of measure for electrical resistance, or siemens (S,) the unit of measure for electrical conductance.

Baseline galvanic skin response can vary greatly from person to person, even day to day for the same test subject. Several behavioral and physiological factors affect the amount of resistance measured. The internal resistance of the human body can vary from 300-1000 ohms based on diet, size, and composition. Muscle and nerve tissue have a lower resistance than bone and fat, and men typically have a lower body resistance than women. Skin composition and condition can also affect GSR measurements, which can have a resistance ranging from 50,000-1,000,000 ohms. A thick stratum corneum and dirty skin will have a greater resistance to electrical current than clean skin and a thin stratum corneum. Context can also affect GSR levels. Testing in a laboratory setting will yield different results than mobile, real world testing (Westland 2011).

Technical factors, such as electrode placement, can influence measurements as well. Electrodes that are closer together will have a lower resistance than those farther apart. As with most electrical circuits, avoiding a loose contact, in this case at the skin-metal interface, is important for accurate readings. Movement can also introduce artifacts to the GSR signal by varying the pressure between skin and electrode at the contact site. Electrode type is another factor. Electrodes made of any conductive metal will work, but silver electrodes have been shown to be the best conductor for this application (Poh et al. 2010, Westland 2011). It should be noted for safety that the voltage applied to the skin should not exceed 0.5 V DC, the voltage source should not be a 120 V wall outlet, and electrodes should never be placed on opposite sides of the body (Cornell 2012).

Changes in the galvanic skin response signal can have a variety of sources, and it should not be relied on heavily to provide insight to emotional nuances by itself. However, common features of the signal have been identified and linked to stimuli. The GSR signal is generally composed of two elements, the tonic and the phasic. The tonic component, also referred to as the skin conductance level (SCL,) is composed of low frequency baseline changes in the range of 0-0.05 Hz. This overall level is a measure of psychophysiological activation and can vary greatly from person to person. Phasic components are the faster responses to specific stimuli, typically in the range of 0.05-1.5 Hz, and are also referred to as skin conductance response (SCR) events. Figure 1 shows a typical SCR event with several key features that are used to identify them and also compute the magnitude of the startle response. These features include the SCR amplitude and the recovery time. Latency is typically 1.5-6.5 seconds after the stimulus. Several studies have established the link between known startle events and SCRs. Generally, stress causes an elevated skin conductance level and more frequent skin conductance response events (Schumm et al. 2008).

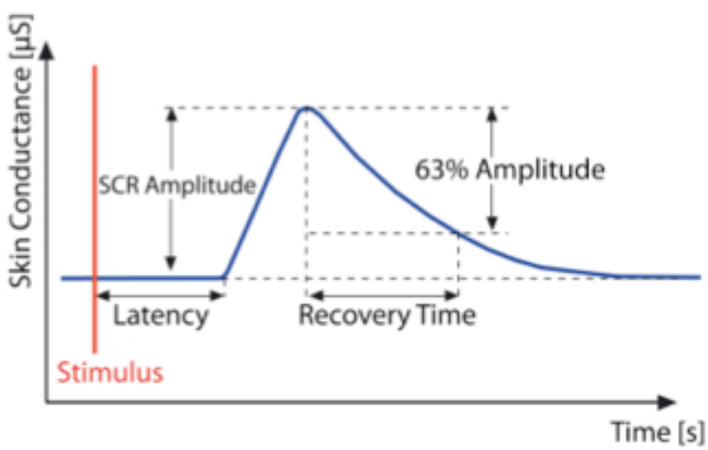

Figure 1: Example SCR with relevant features (Kappeler-Setz 2011)

Subjects that are not seated generate a large number of movement artifacts. Schumm et al. identify these as non-specific skin conductance responses (NS.SCR). They conclude that even with digital signal processing to filter tonic and phasic elements separately, NS.SCRs still make it difficult to identify startle events (Schumm et al 2008). In an effort to gather galvanic skin response data outside of a laboratory environment, Westeyn et al. developed ActionGSR. This device includes accelerometers in the sensor package, allowing movement artifacts in the galvanic skin response signal to be identified and ignored. Figure 2 shows example results from the ActionGSR experiment (Westeyn et al. 2006).

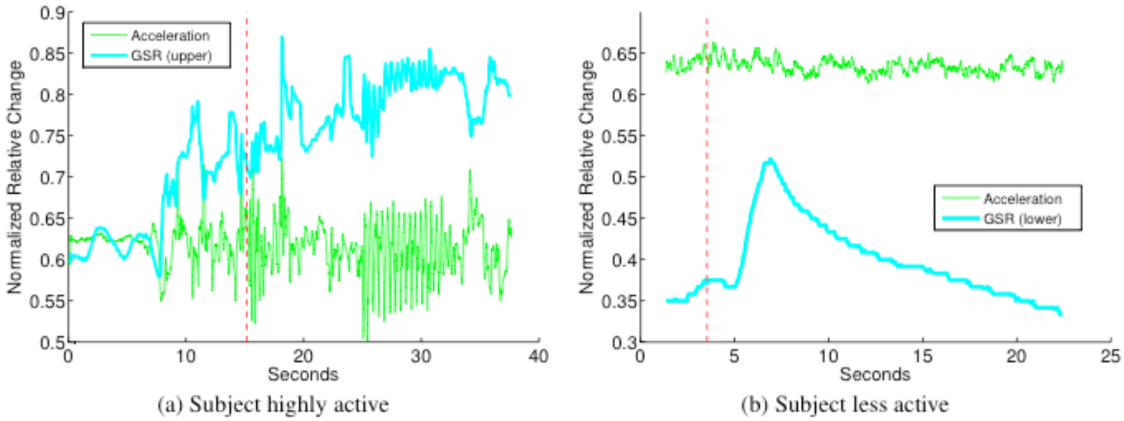

Figure 2: A comparison of galvanic skin response signal (a) during vigorous movement, and (b) during minimal movement. The dashed vertical lines represent a stimulus event (Westeyn et al. 2006).

It has been shown in experiments that SCR events tend to habituate over time. Each successive time a subject is presented with a startle event, the SCR amplitude decreases. Latency between the stimulus and the SCR event also increases as the subject adjusts to the stimulus. One way to lessen the habituation effect is to allow the subject to shift attention away from the stimulus by providing an appropriate length of time to pass in the inter-stimulus interval (Biomedical Signal Analysis Group 2012).

The galvanic skin response signal by itself is not useful for identifying specific emotions. This biosignal is most appropriate for indicating arousal if a person is either calm, or excited. The amplitude for both the overall skin conductance level and skin conductance response events indicate level of arousal relative to the baseline reading. The signal can be quantified in units of electrical conductance or resistance, but these values do not mean much on their own because of the wide range of values possible given the number of influencing factors. Rate of change, range of values, as well as identifying SCR events, provides the information needed. Emotional valence, whether a reaction is negative or positive, is best determined with other methods.

Research into the galvanic skin response dates back to 1791 with the invention of the first electrical device for detecting biosignals by Italian physiologist Luigi Galvani. Sometimes referred to as Electrodermal Response (EDR) or Electrodermal Activity (EDA,) the phenomenon continued to be studied by physiologists and psychologists as a way to detect emotions through the beginning of the twentieth century. A study in 1906 by Carl Jung on the galvanic skin response and word association made the practice popular with psychotherapists. In the 1930s, the technique became even more popular and continued to evolve after the Chicago police department began using polygraphs in their forensic work. Polygraphs became and remain to this day to be the largest market for this technology. Since then, GSR sensors have been adopted for various biofeedback applications. Some of these applications include controlling seizures, relaxation and stress management, analysis by spiritual groups, as well as some novel game interfaces (Westland 2011).

Despite the availability of low cost microcontrollers, use of the galvanic skin response in commercially developed games is limited. In 1997 Konami released *Tokimeki Memorial Oshiete Your Heart*, a dating simulator RPG that uses GSR and heart rate sensors to monitor the player's response to simulated social situations (Gilleade 2005). Since 2001, the biofeedback game *The Journey to Wild Divine* has been available for personal computers. The game directs users through several relaxation activities and monitors the player using GSR and heart rate finger clip sensors shown in Figure 3 (Nacke 2011).

Figure 3: Wild Divine's iom, a combination GSR and heart rate sensor (Wild Divine Inc. 2012)

Several research projects have explored the use of GSR as both a control signal and for biofeedback in games as well as the galvanic skin response in user experience studies. Gasperi conducted a simple test with a modified Lego Mindstorms kit to monitor his GSR levels while playing an "intense" video game. Figure 4 shows the results of this test as changes in skin resistance over time notated with some relevant game play events (Gasperi 2009).

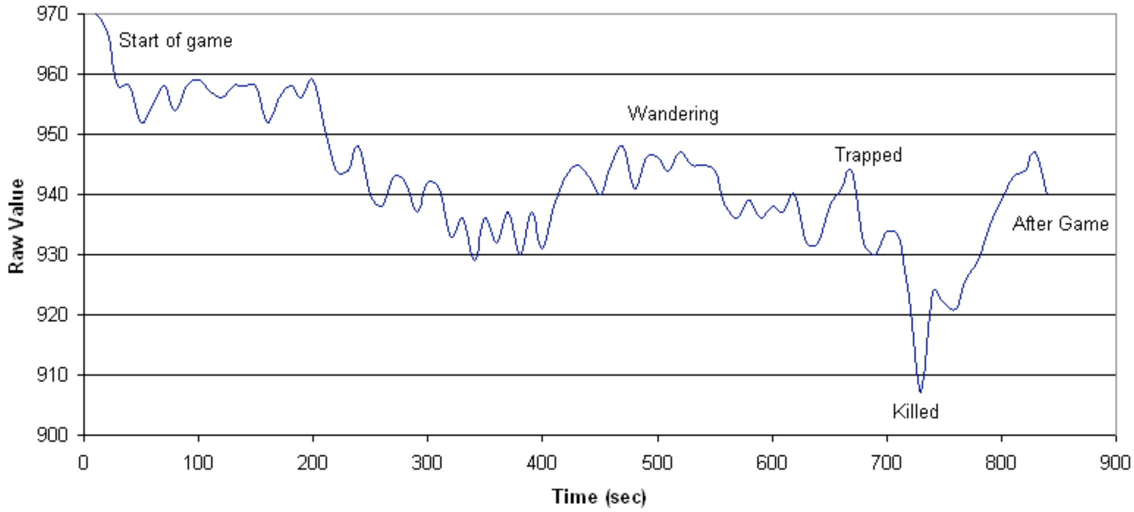

Figure 4: Skin resistance changes while playing a video game (Gasperi 2009)

Bersak et al. proposed that a subject is affected by biofeedback as well as by how it is presented. They explored the use of real time biofeedback with *Relax to Win*. This racing game requires the player to lower his GSR signal level through relaxation in order to go faster. The group found that players were able to relax more with each successive play-through (Bersak et al. 2001).

Sakurazawa et al. developed *Balloon Trip*, a game that requires the player to navigate through an obstacle course while remaining calm. The game uses the galvanic skin response to measure the arousal level of the player. GSR input controls the rate of obstacle generation, where increased arousal translates to more obstacles. The developers of the game proposed that in shared gaming experiences, this implementation of biofeedback increases both player and audience engagement. Players were found to be more engaged when playing before an audience than when playing alone. The game was tested with and without GSR level displayed on screen. The group also found that displaying GSR levels increased player agitation, but was more interesting for both player and audience (Sakurazawa et al. 2004).

Dekker and Champion used input from the Wild Divine iom sensor in Figure 3 to modify Valve Corporation's first person zombie shooter *Half Life 2*. They used galvanic skin response to modify game design and game play elements based on the player's affective state. Depending on how the player reacted to the game, the biosignal input could enable stealth mode, increase a weapon's damage factor, change the player's field of view, or change the spawning locations of enemies. Results from this experiment were mixed, perhaps from testing too many factors at one time (Dekker and Champion 2007).

Nacke et al. investigated the relationship between game audio and biosignals in their user experience test. The experiment collected GSR and face muscle movements while playing a modified map from *Half Life 2*. Their hypotheses that tonic levels for both biosignals would increase when players experienced the game with music and sound effects and decrease when playing in silence were not supported. They concluded that phasic responses to game audio should be tested and correlated with specific game events (Nacke et al. 2010).

The development company Valve has also been investigating the use of GSR in games. One potential application of interest is the passive viewing of biofeedback data. In a multiplayer game, players could detect when a teammate is in trouble or observe the suffering of an opponent from the on-screen display of arousal levels. Using GSR as a direct input, the developer is also testing the modification of game play based on biosignals through adaptive real-time difficulty adjustments. Using their cooperative first person shooter, *Left 4 Dead 2*, Valve was able to detect when a player is overwhelmed and allow periods of relaxation. This feature also gives the developer valuable feedback on player experience, allowing some insight into what types of game events elicit a player response and the level of that response. The company has also tested the use of player arousal level to adjust timed tasks in their shoot'em up title *Alien Swarm*. The player is given a timed task, with the timer indexed to arousal level. If arousal level is high, the timer speeds up, if it is low, the timer slows down.

Several problems have been identified by these tests. In the *Alien Swarm* test, where player panic might be reinforced by the implementation, a feedback loop is possible. Adding a decay factor to the biosignal control variable could prevent this from happening. Researchers at Valve found that while biosignals make viable control inputs, the relationship between arousal and game events is not always clear. It is also very labor-intensive to adjust the biosignal-to-game events control algorithm. It is a simple task to link a parameter to GSR input, but it is much more difficult to make the experience fun and compelling. (Ambinder 2011).

Heart Rate and Blood Volume Pulse

Heart rate is an involuntary function of the autonomic nervous system that changes under fight-or-flight conditions. As a response to stress, heart rate will increase as the body prepares for action. Measuring and analyzing this biosignal provides several features for evaluation such as the beats per minute (bpm,) heart rate variability (HRV,) and the strength of the signal. One does not need special equipment to observe or even measure this biosignal. Pulse can be measured and approximated manually, but in order to obtain more exact measurements for better analysis, another method of detection is necessary. One such method is to measure blood volume pulse (BVP) through pulse oximetry.

The technique of pulse oximetry takes advantage of the light absorption characteristics of blood cells called hemoglobin. Oxygen enters the body through the lungs where it is picked up by hemoglobin. These cells are referred to as oxygenated hemoglobin, and once the oxygen payload is delivered, the hemoglobin is deoxygenated. Each type of hemoglobin absorbs or reflects red and infrared light at different levels. Red light has a wavelength of 600-750 nm, and infrared has a wavelength of 850-1000 nm. Deoxygenated blood cells absorb more red light and reflect more infrared light than oxygenated blood cells. Light is shone through a reasonably translucent site with good blood flow like a finger, toe, pinna, or earlobe. Any measurement site will have both constant and variable levels of absorption, with skin, tissue, and veinous blood levels remaining constant and arterial blood changing with each heartbeat.

Most modern BVP sensors quickly switch between red and infrared LEDs at the transmission point. The light passes through tissue and is captured with phototransistors on the other side of the tissue in the transmission method, or both emitter and receptor may be placed on the same side of the measurement site in the less common reflectance method. The absorbed or reflected levels of light are then compared to measure oxygen levels in the blood; pulse detection is a byproduct of this measurement. For detecting heart rate alone, only one type of light is necessary. The waveform, or plethysmographic trace from a pulse oximeter with only an infrared LED still has periodic shape.

In general, a noise-free waveform of a single heartbeat detected with a BVP sensor will have the shape seen in Figure 5. The direct pulse of blood from the heart causes the initial peak. The lower body reflects this pulse wave, causing a second peak in the waveform. The ripple in between caused by this reflection is called the dicrotic notch.

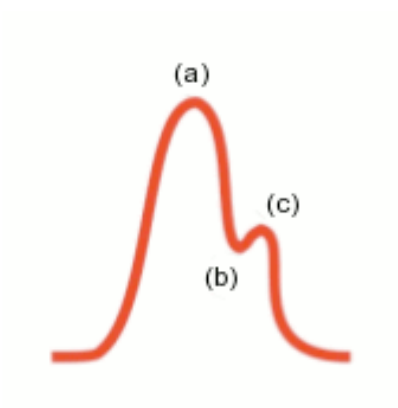

Figure 5: (a) Direct pulse, (b) dicrotic notch, and (c) reflected wave (Thought Technology 2012)

With the heartbeat identified by the direct pulse peak in the waveform, the pulse rate may be calculated. This is accomplished by measuring time between each successive heartbeat, or the inter-beat interval (IBI.) Heart rate is influenced by many physiological factors and the IBI varies constantly. Typical resting heart rate is around 60 bpm, and the average range for activity is greater than or equal to 90 bpm. This minimum to maximum range helps define the level of health of a person, and a certain amount of heart rate variability (HRV) is desirable as it shows adaptability to circumstances. The term is used to describe both the oscillation in the interval between consecutive beats, as well as oscillations between consecutive instantaneous heart rates (Malik et al. 1996). Several factors influence HRV, including blood oxygen and CO_2 levels, blood pressure, body temperature, as well as respiration rate and depth. Paced breathing can show the most dramatic HRV results. These processes tend to maintain stable conditions, but are cyclical. The oscillations of each of these regulatory systems interact, affecting HRV over varying periods.

The Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology proposed several time and frequency domain analysis methods in 1996 that have been widely adopted (Thought Technology 2012). Analysis of HRV for medical applications is typically done after the signal has been measured for a given time window. Time windows are typically 5 minutes for short-term measurements and 24 hours for long-term measurements. Comparing time windows of varying time window sizes is not valid and most of the analysis methods are not suited for real-time analysis (Malik et al. 1996).

Readings may be affected by a variety of factors that can introduce noise to the signal and cause invalid readings. Movement and poor sensor placement are the most common problems. Movement artifacts may cause heartbeats to be missed or extra beats to be calculated. Placing the sensor on a site that is too thick or too dense will give a weak or possibly no reading. Sensor tightness may also limit circulation at the test site. Light interference and electromagnetic devices can introduce noise to the signal, although modern pulse oximeters also measure ambient light and subtract it from the signal. Various medical conditions also can interfere with obtaining accurate readings (Barker et al. 2002).

Despite the simple, non-invasive nature of BVP sensors, only a few commercial game titles have incorporated the feature. In 1998, *Tetris 64* was released for the Nintendo 64 in Japan. The game included a mode called Bio Tetris. Using an ear clip sensor that connects to the Nintendo 64 controller shown in Figure 6, the game adjusts to the player's heartbeat depending on the game play mode selected. In Normal mode, the game becomes easier as the player's arousal level goes up, but in Reverse mode game speed increases along with player arousal (Schneider 1999). *The Journey to Wild Divine*, mentioned in the section on the galvanic skin response, also incorporates a BVP sensor, shown in Figure 3, but game play features are limited to biofeedback exercises.

Current trends for game development using BVP sensors are limited to health and biofeedback games. The cross-platform *EA Sports Active 2* package includes a heart rate monitor to track and display heart rate with exercise games. Other companies have developed BVP sensors, but as of this writing, no products have been released. Nintendo developed the Wii Vitality finger clip sensor to be used with Wii Fitness products, shown in Figure 7. Ubisoft demonstrated the Innergy sensor, shown in Figure 8, at the 2010 E3 Conference. The sensor was demonstrated with a biofeedback training game, shown in Figure 9. Based on the text prompt, it appears to measure the effect of paced breathing on heart rate variability.

Figure 6: BVP sensor pack for use with *Tetris 64* (心理 2009)

Figure 7: Nintendo’s Wii Vitality sensor with Wii remote (Shamoon 2009)

Figure 8: Ubisoft's Innergy sensor (Shaul 2010)

Figure 9: Ubisoft's biofeedback training demo for the Innergy sensor (Gilleade and Fairclough 2010)

The apparent cancellations by Nintendo and Ubisoft of their respective BVP sensors may be an indication that the companies encountered too many development problems to release the devices. The technique is especially vulnerable to movement artifacts, and the long time windows necessary for analyzing HRV may make the incorporation of the signal too difficult. Given the success of Microsoft's Kinect camera sensor, there may be an alternative input method for heart rate in the future. Wu et al. recently demonstrated the ability to detect pulse using a new method of real-time video analysis. The method works with different skin tones and small movements (Wu et al. 2012).

Other Biosignals

There are several other biosignals that can provide information about a person's affective state, including brainwaves and the electrical signals generated by muscle movements. Each has advantages and disadvantages as an input signal for games, with varying degrees of difficulty of implementation.

Blood volume pulse is not the only method for detecting heartbeat. An electrocardiogram (ECG) is the display of the electrical activity of the heart over time by detecting and amplifying electrical changes in the skin caused by heart muscle activity (McGill University 2012). Measuring ECG requires more sophisticated equipment than BVP and is slightly more invasive. The waveform, shown in Figure 11, is more defined and has more identifiable features in one cycle than the BVP signal. The ECG signal has a sharper peak, seen in Figure 11(c), allowing for better detection of the inter-beat interval. The signal is measured by placing three electrodes on the chest or arms, ideally in one of the configurations shown in Figure 10. Skin preparation and conductive gel are necessary for the best signal. Compared to the simplicity of the BVP sensors shown in Figures 7 and 8, a commercial ECG sensor for home entertainment is not very practical.

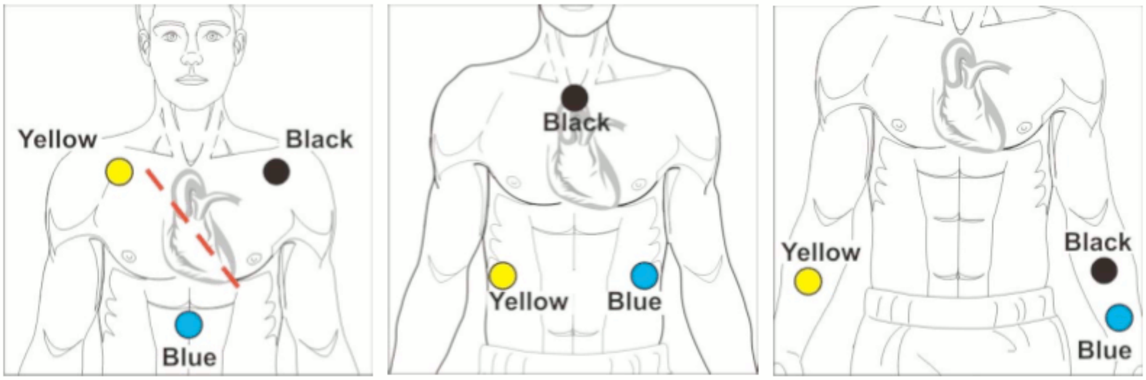

Figure 10: Electrocardiogram electrode placement options (Thought Technology 2012)

Noise may be introduced to the ECG signal in several ways. Measuring equipment is susceptible to line interference from improper electrical grounding. Muscle contractions near the sensor sites may also introduce unwanted artifacts. A bad contact may introduce DC offset, and improper electrode placement can result in polarity issues. Proper measurement requires a trained technician, making this biosignal better suited for medical and laboratory applications than as a control signal for video games (Thought Technology 2012).

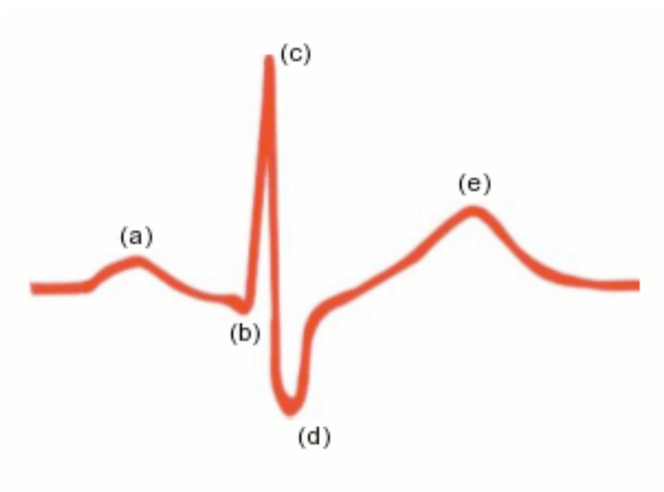

Figure 11: Features of an electrocardiogram signal (a-e) represent the depolarization and repolarization of the atria and ventricles, or one heartbeat (Thought Technology 2012)

Several research projects have measured the effects of video game play on heart rate using ECG. Ivarsson et al. monitored heart rate and movement in children while playing a violent game and a non-violent game. Higher heart rates were found during violent game play, but the study did not correlate heart rate variability to specific game play events (Ivarsson et al. 2009).

Panee and Ballard measured heart rate and blood pressure before, during, and after playing *Metal Gear Solid* as part of a larger study on aggression and video games. They found elevated blood pressure levels during violent game play as well, but concluded there are too many psychological factors involved to make any meaningful correlations and recommend further study (Panee and Ballard 2002).

An Electroencephalogram (EEG) is a recording of the frequency, amplitude, and wave shape of electrical activity along the scalp produced by firing of neurons in the brain over time (McGill University 2012). Measurements are taken by placing electrodes along the scalp. Analysis of EEG signals has been shown to trace attention, emotion, and recall (Othman et al. 2009, Wang et al. 2010).

EEG has several advantages over other brain scanning techniques such as fMRI and PET scans. Measuring the signal is relatively easier to implement, less invasive, and cheaper than other techniques. Response times are fast and the signal can be measured in real time. EEG is limited by the fact that it is only useful for measuring signals present near the skull (Westland 2011).

Several commercial EEG sensors are currently available. These interfaces are intended for use with games, such as the Emotiv EPOC seen in Figure 12, the Neurosky Mindset, and the OCZ Neural Impulse Actuator. These interfaces come bundled with biofeedback software or are targeted at developers looking to integrate biofeedback in to their games (Nacke 2011).

Figure 12: Emotiv EPOC EEG headset (Emotiv 2012)

Pope et al. demonstrated that EEG input is a viable control signal in a "biocybernetic system." This research was concerned with the human operators of mostly automated computer systems. In such a system, the operator is relegated to monitoring functions and spends little time controlling the system. This challenges the ability of the operator to maintain the attention necessary for optimal situation awareness. In their experiment, the researchers demonstrated that by measuring operator engagement through EEG, a balance of monitoring and controlling functions could be achieved that would keep the operator alert (Pope et al. 1995).

Electromyography (EMG) is the recording of electrical activity generated by muscle cells during movement. Similar to ECG, three electrodes are placed on the desired muscle group, and the time-varying voltage level is measured (McGill University 2012). EMG signals can be the result of intentional motor action such as raising an arm, or an emotional reaction such as frowning. Unlike galvanic skin response and heart rate, this biosignal is much easier to implement as either an explicit or implicit control depending on the action.

In the 1980s, Atari began development of a headband EMG sensor called the Atari Mindlink. The sensor was intended to be an explicit controller that measured muscle movements in the forehead, but the project was cancelled (Vendel 2011). Research on EMG as an affective signal focuses primarily on recording facial expressions to be correlated with other affective signals (Conati et al. 2003, Nacke et al. 2010).

The work presented here only scratches the surface of past and ongoing research into affective systems and the use of biosignals to enhance human-computer interactions. These examples show that biosignals can be used to recognize low levels of human affect when measured and analyzed properly. Using the information discovered by medical researchers, psychologists, and affective system designers, it is up to the game designer to find new ways to engage players. In the next chapter, I will lay out a method that attempts to achieve this using biosignals to control game music.

Chapter 3: Method

THE BIOREADER MUSIC SYSTEM

The goal of this project is to test the design possibilities of using biosignals as implicit controls of video game music. The system should add another dimension to the game play experience by driving an adaptive music system that varies based on the player's affective state without requiring explicit input from the player. A prototype music system and sensor circuits were developed and tested with four video games from different genres. The Bioreader music system was developed separate from the game play system in order to learn as much as possible before proceeding with the labor-intensive task of modifying an existing game audio engine. Testing in this general way also allows for rapid prototyping and evaluation of design features as well as testing the system with multiple game types.

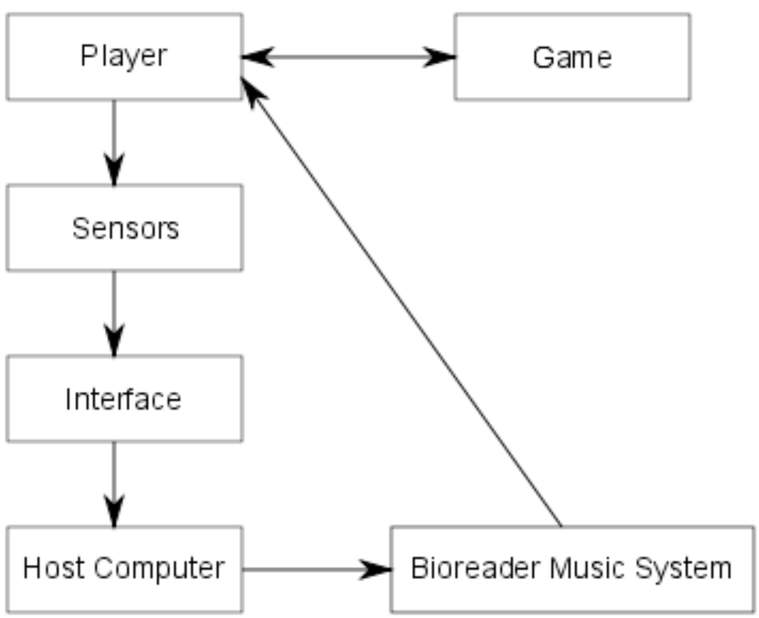

Figure 13: The complete biofeedback system

Hardware

Two biosignals were chosen as inputs for the Bioreader music system, the galvanic skin response and heart rate. Both the simplicity of the signals and sensors involved, as well as the established connection between biosignals and affective state changes laid out in the previous chapter make these two signals ideal for use in a game biofeedback system. The process begins by using GSR and BVP sensors to collect biosignal data from the player during game play. The signals are amplified, filtered, and converted from analog to digital signals by a microcontroller interface before input to the host computer. Once in the digital domain, the signals are processed further to remove remaining noise for proper display and analysis. The processed biosignal input is then fed back to the player as changes in music intensity.

Galvanic Skin Response Sensor

Galvanic skin response sensors consist of two electrodes. Typically a GSR signal is very weak, in part due to the low voltages that must be used to safely measure this biosignal. Measurement may take place anywhere on the skin, but to obtain the best signal, feet and hands work best. The most common type of GSR electrode attaches to the fingers, with contact made on the palmar side of the hand. Finger electrodes were chosen for this test for several reasons. The fingers are easier to access than feet, and hand-held game controllers, such as a game pad or a mouse, are likely places to include a GSR sensor when considering future hardware development.

The first prototype GSR sensor built for this project was modeled after the sensor described by Gasperi in his report on GSR measurements during game play (Gasperi 2009). This simple sensor was constructed from Velcro strips, aluminum foil, and wire. The foil is cut into strips and attached to one side of the Velcro with a wire attached similar to what is seen in Figure 14. The resulting sensor was found to be inadequate. Signal level was too low, even with amplification, and it was found that the aluminum foil traps too much skin moisture, artificially elevating the GSR signal over time. Contact between the foil and wire was also poor. New electrodes were built, replacing the aluminum foil with O-ring connectors (shown in Figure 14,) found at a local hardware store (Wang and McCreary 2012). The rings provide better surface contact and signal strength while also allowing better ventilation. During testing, the electrodes were attached the middle phalanx of the ring and small fingers of the left hand, as seen in Figure 15.

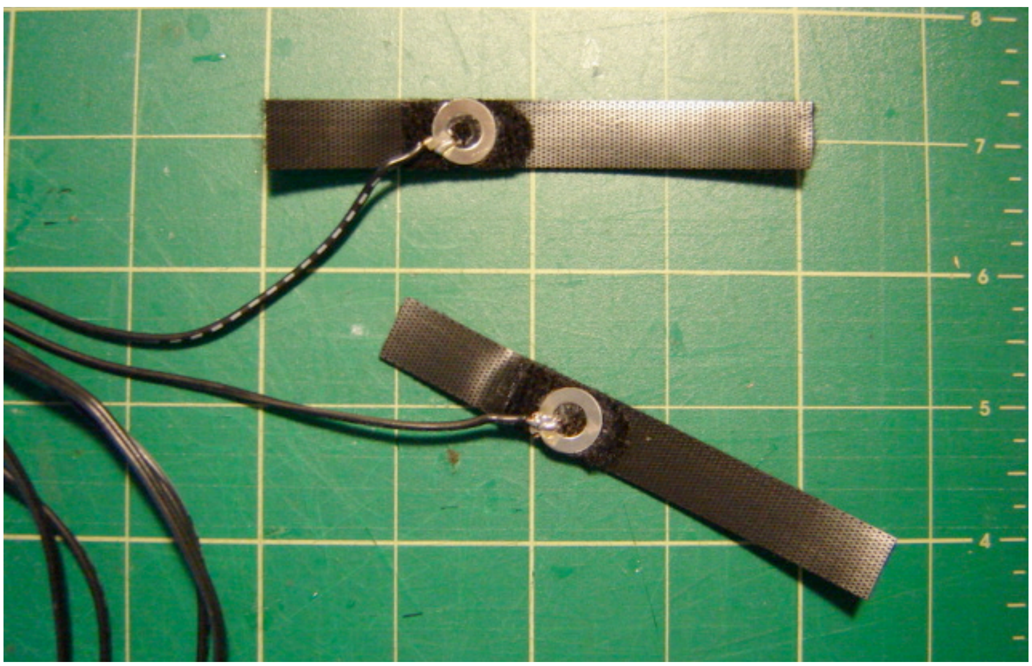

Figure 14: Final GSR sensor construction

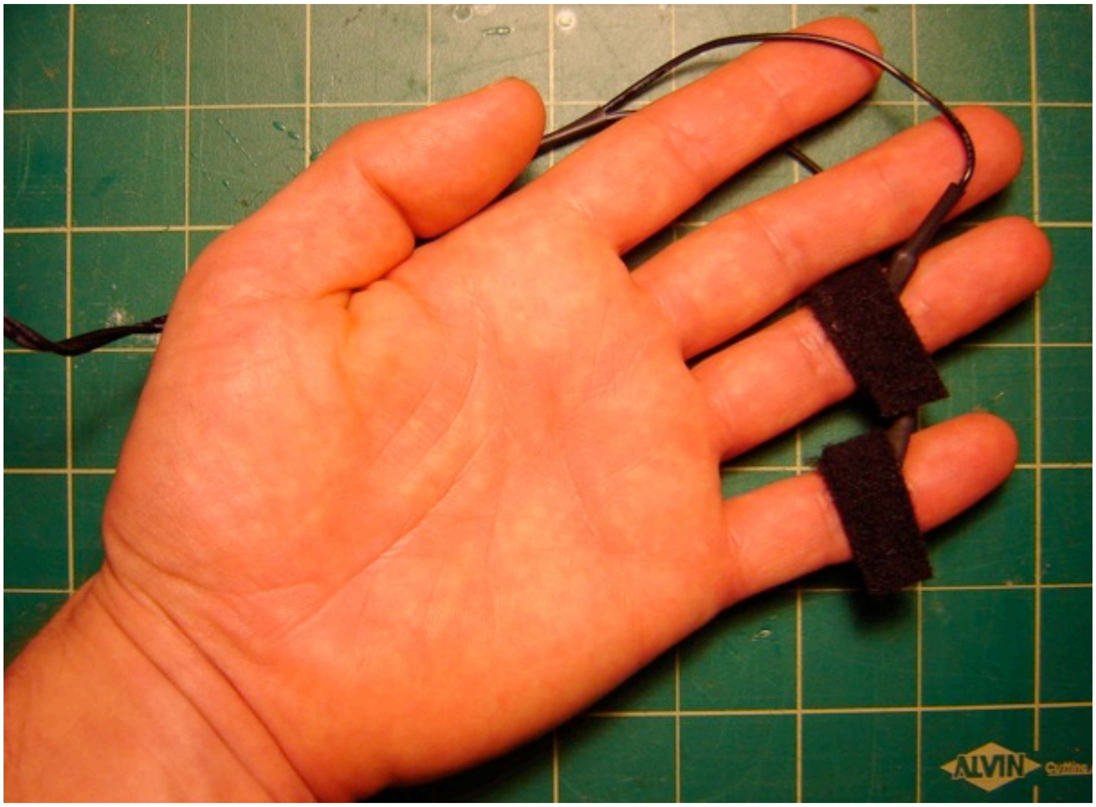

Figure 15: GSR sensor placement

A circuit designed by Wang and McCreary is then used to amplify the GSR signal. (See Appendix A for the circuit diagram and Appendix B for the complete parts list.) A voltage divider lowers the 5 V power supply to 0.5 V across the electrodes, to safely measure the galvanic skin response. The electrodes of the GSR sensor form one leg of a Wheatstone bridge, which is used to measure the unknown electrical resistance. The signal is then passed through two amplifying stages followed by a low pass filter with a cutoff frequency of 0.5 Hz to reduce noise (Wang and McCreary 2012). This signal is fed into port A0 of an Arduino Uno microcontroller for analog to digital conversion and input to the host computer.

Blood Volume Pulse Sensor

The BVP sensor built for this project is an infrared ear clip design that uses the transmission method to detect the pulse as changes in blood volume. Although the finger clip design is the more common type of BVP sensor for gaming applications, the ear lobe was chosen as the measurement site to minimize movement artifacts and keep the hands relatively free for game control. The infrared emitter and collector were placed inside cowls to reduce interference from ambient light as seen in Figures 16 and 17.

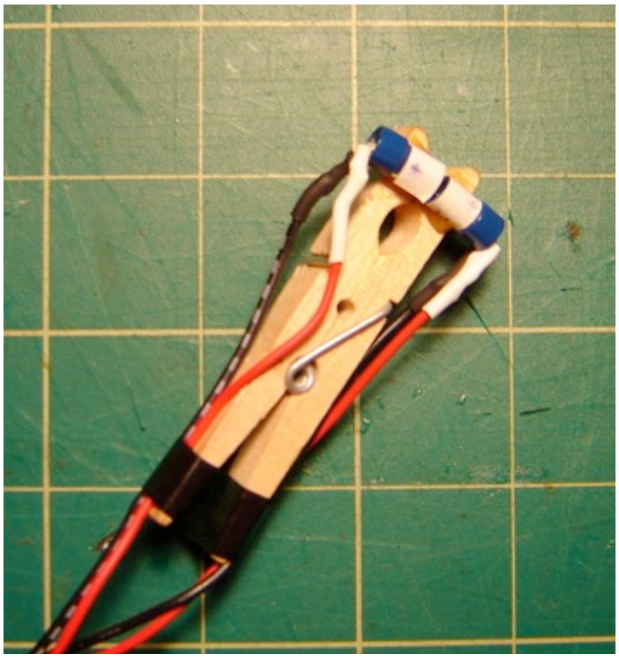

Figure 16: BVP sensor

The signal from the photodiode is amplified by a modified version of the circuit presented in *Electronics Now* (1992). The original version of this circuit uses the reflectance method but a separate emitter and collector pair was substituted for the single photosensor in the original circuit. (See Appendix A for the modified circuit diagram and Appendix B for the complete parts list.) The output of the amplifier circuit is connected to port A1 of an Arduino Uno for analog to digital conversion and input to the host computer.

Figure 17: BVP sensor placement

Arduino Uno

The interface chosen for this project is the Arduino Uno microcontroller board, shown in Figures 18 and 19. The board's low price, ease of use, comprehensive documentation, and large online community were important factors in this selection. The Arduino board was used only for analog to digital conversion in this case, but the board could also be programmed to handle the digital signal processing described in the Software section. The availability of smaller wireless Arduino boards makes this line of interfaces ideal for future development projects.

The Arduino Uno has six analog inputs and USB connectivity for converting signals from the prototype sensor circuits and communication with the host computer running the digital signal processing and music system software. Analog to digital conversion runs at a sample rate of 10 KHz with 10 bits of resolution. The board is USB powered, and also supplies the sensor circuits with 5 V DC (Arduino 2012).

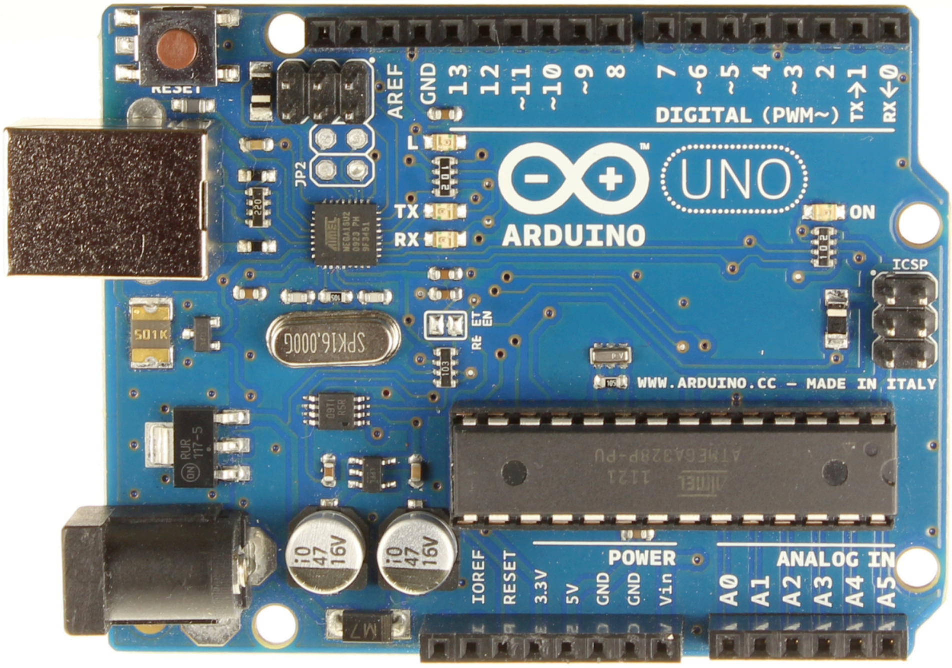

Figure 18: Arduino Uno microcontroller

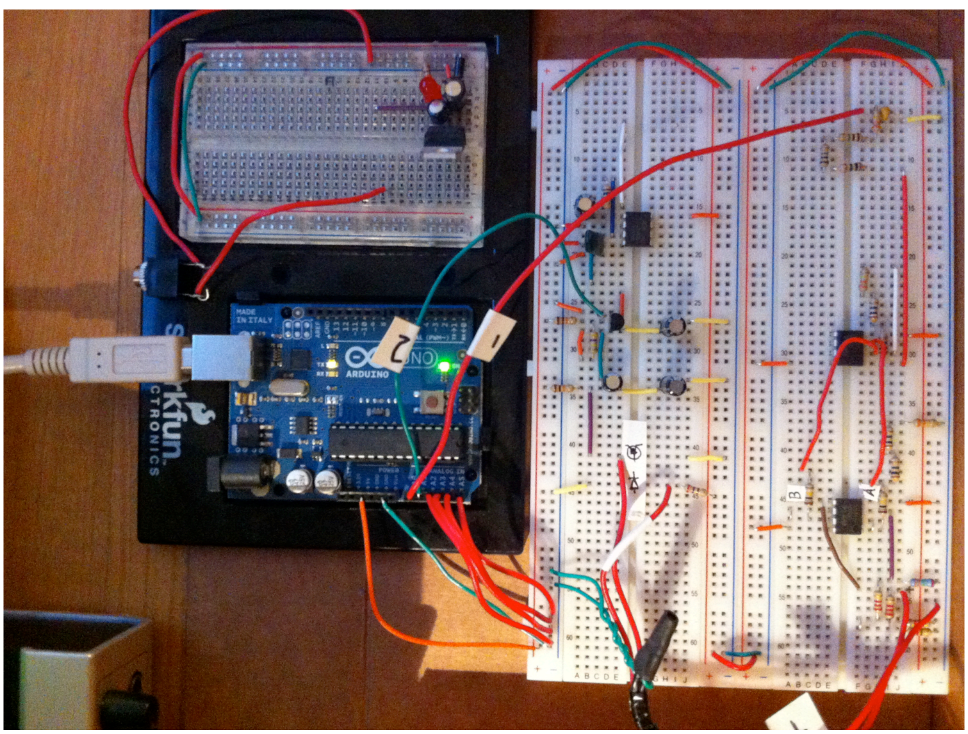

Figure 19: The GSR and BVP circuits connected to the Arduino interface

Software

The Arduino Uno is completely controlled by software on the host computer for faster testing of software changes. Communication between the Arduino Uno and software on the host computer is handled by the generic communication protocol Firmata. Firmata runs at 57.6 kbps on the Arduino Uno (Firmata.org 2012). The graphic scripting language Pure Data (Pd) is the controlling software used for this project (Pure Data 2012). Firmata firmware is uploaded to the Arduino Uno from the host computer to enable communication between the Arduino board and the host computer. The related object class for Pd, Pduino, written by Hans-Christoph Steiner, must also be installed on the host computer (Steiner 2012). Once the installation is complete, changes made in Pd can be tested in real time without the need to upload firmware changes to the Arduino after each iteration.

A program designed in Pd is built with objects, much in the same way that a text-based program is built with functions. Pd objects will be represented by the name of the object in [brackets] for the following description. For the most part, the signal chains for both biosignals are identical, as seen in Figure 20. Figure 21 shows the front end of the Bioreader. See Appendix C for the complete Bioreader program.

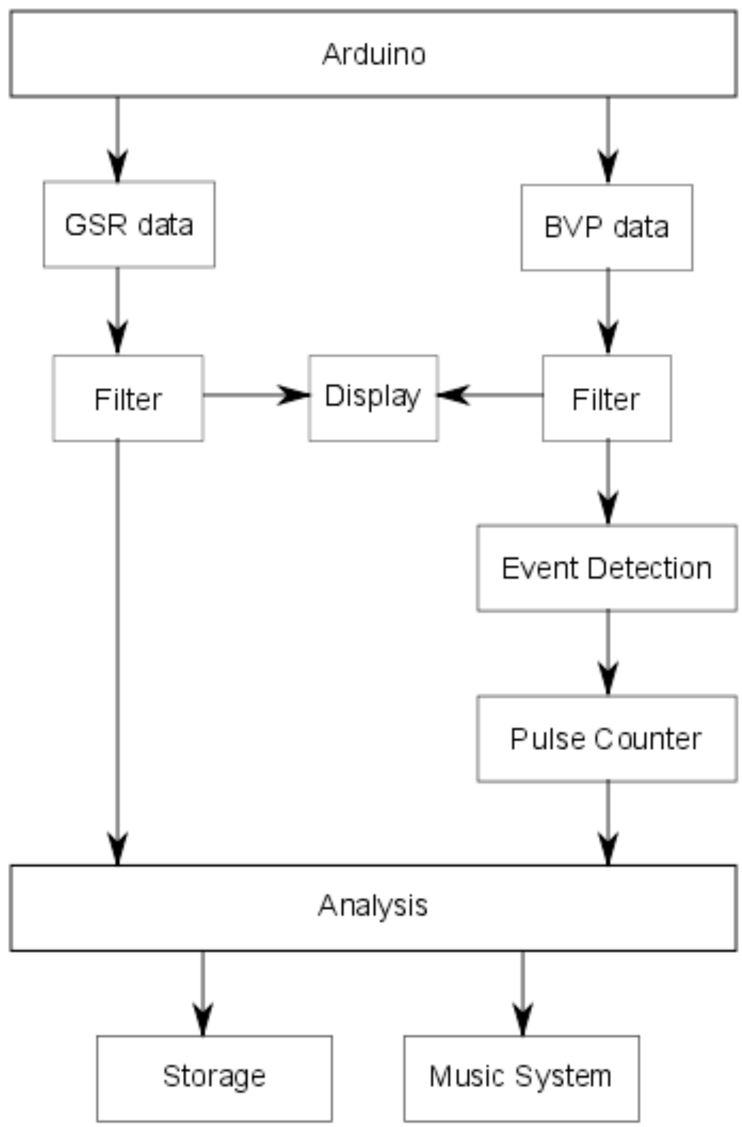

Figure 20: The Bioreader software system

On loading the Bioreader software, all data storage objects and variables are initialized and can also be reset manually using the red “reset_graph” button. Incoming data from the Arduino is accessible through the [arduino] object. This object selects the port to read incoming data from on the host computer and also tags incoming signals with labels that allow sorting by type and microcontroller port number. Analog input is switched on and off by the yellow “toggle_data” switch. Inputs A0 (the GSR signal,) and A1 (the BVP signal,) are routed from the [arduino] object using the [analogRoute] object for filtering, display, and analysis. After routing, both signals are down-sampled using [speedlim] to prevent event-driven signal processing operations further down the signal chain from overloading the host computer CPU. The GSR signal is resampled at 10 Hz, while the BVP signal is resampled at 100 Hz. At this point the raw GSR signal is still quite low, even after passing through the amplification circuit, and is scaled up by a factor of 1000 to prevent the need for counting excessive decimal places in later operations. As mentioned previously, the units of measure of both biosignals are irrelevant as the important operation in this application is calculating the running mean and slope of the signals while comparing current readings to the baseline readings.

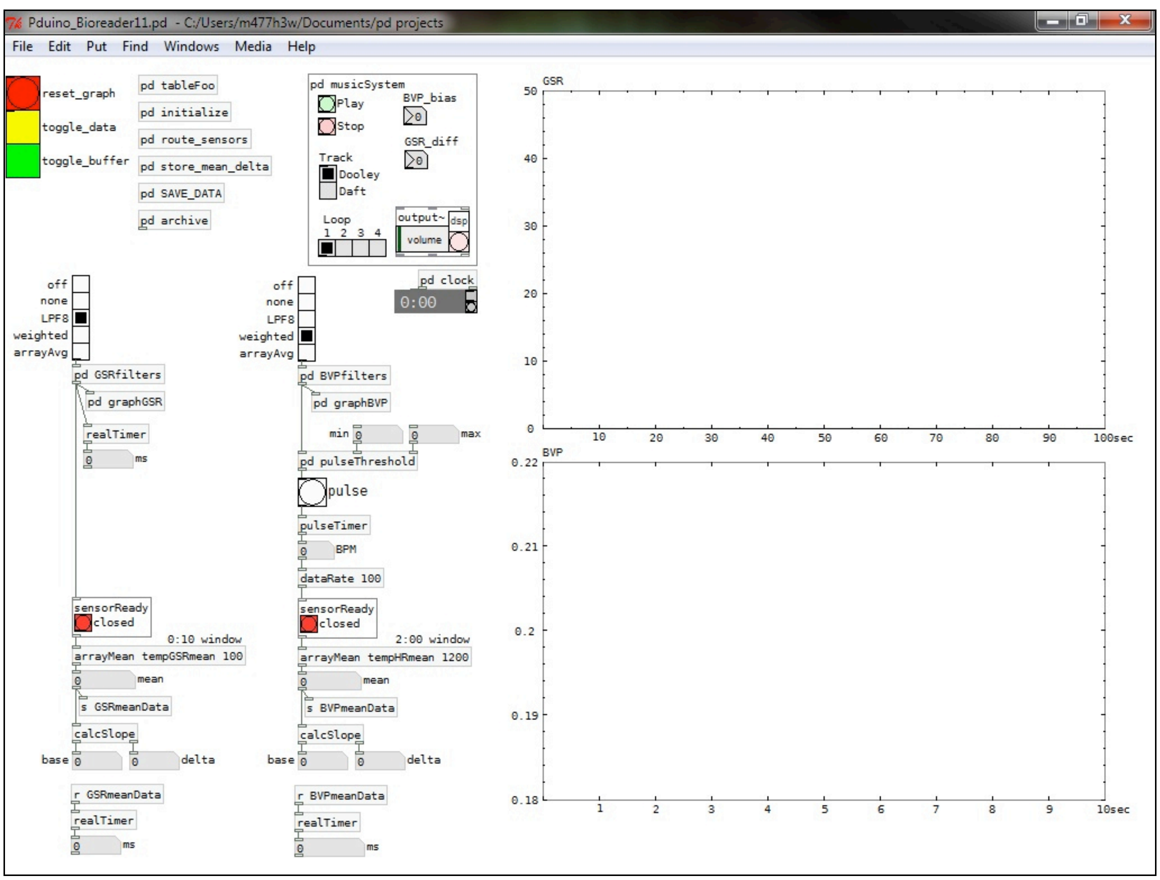

Figure 21: The Bioreader front end, version 11

The next stage of the Bioreader is the filter section. Hardware filtering in the circuits needed to be supplemented by digital signal processing, as there was still excessive noise in the raw input signals. Three filter designs were implemented and tested before play testing commenced. The signal paths for both biosignal inputs contain all filters for quick comparisons. Filter routing is handled by the initialization function on load, but can be selected manually as well.

The low pass filter [LPF8] is an eight-pole finite impulse response (FIR) filter based on the following:

$$y[n] = (a_0 * x[n]) + (a_1 * x[n - 1]) + \ldots (a_i * x[n - i])$$

where y is the output, x is the input, a is the filter coefficient, and n is the current sample (Roads 1996, 406). The next filter is a weighted average filter with an adjustable weight for fine-tuning. This filter is based on the following:

$$y[n] = (w * x[n]) + ((1 - w) * x[n - 1])$$

where y is the output, x is the input, w is the weight from 0-1, and n is the current sample. The final filter is an averaging array that continuously reads input values into an array with 100 elements and calculates the running average (Gray 2008).

After the filter block, the signal branches to the analysis block and the display block, with each branch requiring slightly different signal processing. The main purpose of the display block is to provide visual feedback for proper sensor placement. This feature was also relied on heavily for the evaluation of the different filter types before final implementation. The display block limits the incoming signal to the bounds of the graph windows to prevent off-screen spikes, sets the graph write speed, and then writes incoming values to the appropriate array using the graphical table feature of Pd. The GSR graph displays 100 seconds of signal while the BVP displays 10 seconds of signal. This shorter display period is necessary because proper placement of the BVP sensor requires finer detail. The display block was not designed to provide visual biofeedback for the player, but instead it is for calibration only and is not intended to be viewed during game play.

The BVP signal requires additional processing after the filter block to detect and calculate pulse rate. The first step in calculating pulse rate is to detect the heartbeat event. This is handled in the [pulseThreshold] object using an upper and lower threshold as seen in Figure 22. First the incoming signal is tested against the lower threshold. When that threshold is crossed, a pulse event message is sent and the signal is tested against the upper threshold. Once the upper threshold is crossed, the signal is routed back to the block that tests for a lower threshold crossing. These limits must be calibrated for each test session. This feature prevents the small ripples close to the lower threshold from causing multiple triggers (Puckette 2012).

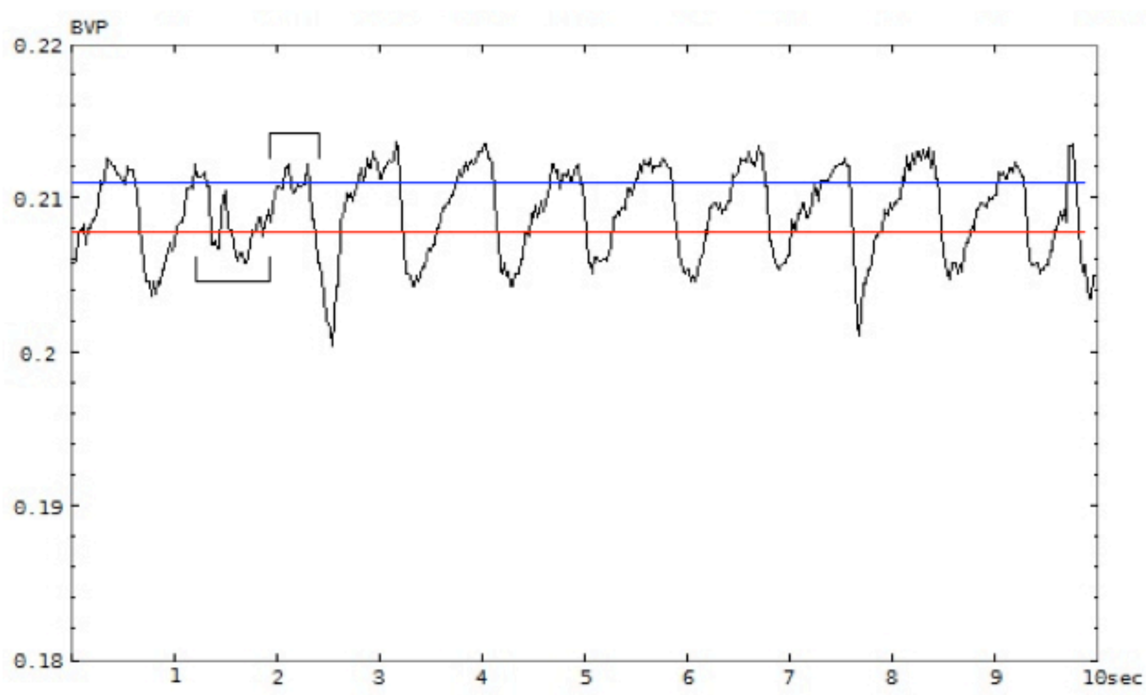

Figure 22: Upper (blue) and lower (red) thresholds used to detect heart beat events. The ripples at 1.5 and 2 seconds will be ignored by the system.

The next step in pulse rate calculation is to count the time interval between consecutive heartbeat events. The [ignoreFirst] object was originally created for the analysis block, and is recycled here to work around an issue with how inputs are handled by the [realtime] object. The [realtime] object counts elapsed real time from a start event or a reset event. The [ignoreFirst] object routes incoming heartbeat events in a way that continually resets [realtime] while measuring the elapsed time between two consecutive events. Elapsed time is output in milliseconds, so [realtime] is followed by an [expr] object that was defined to convert milliseconds to beats per minute. The continuously calculated heart rate is then passed to the moving average filter object [mavg] which smoothes the running heart rate using the previous 12 incoming values. This feature was added to compensate for the extreme beat to beat drift observed during initial testing, most likely due to the phenomenon of heart rate variability. The resulting stream of running pulse rates is up-sampled to a 10 Hz signal by the [dataRate] object to allow for proper handling by the following analysis block which is time-based, not event-based.

Both signal paths incorporate a [sensorReady] object before the analysis block that is toggled by the green "toggle_buffer" switch. This gate prevents artifacts caused by placing the sensors from polluting the data storage arrays and is also used to stop input to the analysis block without switching off sensor input. The [arrayMean] object then calculates the mean of the incoming signal for a given time window. The object differs slightly from the averaging array filter in that it periodically calculates the average for incoming data instead of giving a running average. GSR mean values are calculated every ten seconds, and heart rate mean values are calculated every two minutes. This longer time window was thought to be necessary to prevent excessive jitter caused by heart rate variability based on the use of a five minute window used in medical applications (Malik et al. 1996). The mean values are then passed to the data storage block, the music system, and the final analysis block, where slope is calculated. The [calcSlope] object contains the [firstDiff] object, which calculates the difference between the current and previous mean values. The [ignoreFirst] is also used here to route the baseline mean value to the music system as well as to send running slope values to the data storage block.

The data storage block receives mean and slope values for each signal and writes them to a text file for later statistical analysis. Incoming values are first written to an array using the array push method, which allows values to be written to an array without knowing the final size of the array. New values are pushed into the array as the size is changed dynamically. When sensor input is toggled off, the tester is prompted by a pop-up window to save all mean and slope values to text files through the [SAVE_DATA] sub-patch.

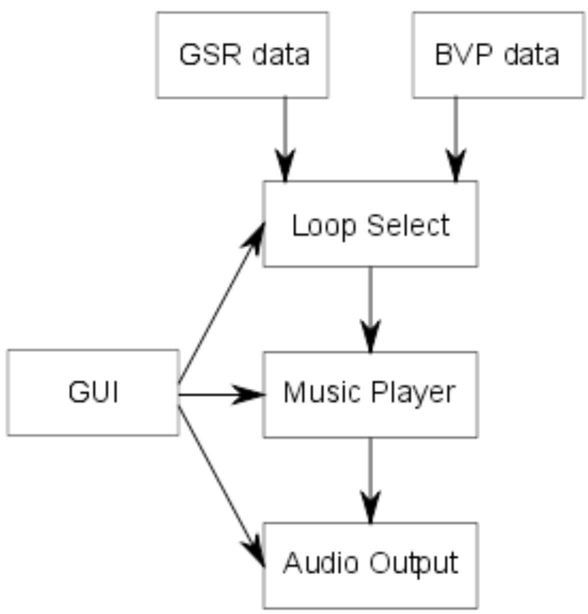

Figure 23: The music system

The music system contained in the [musicSystem] sub-patch is a looping audio player that changes music intensity in real time based on biosignal input. Playback begins with biosignal data capture, which is triggered with the green “toggle_buffer” switch. Two types of music are available for playback, techno and orchestral, and must be selected manually depending on the style that is considered most appropriate for the genre of game being tested. Each music type consists of four loops, beginning with a relatively calm baseline loop and with each successive loop escalating in intensity. The music system graphical user interface was designed primarily for debugging as most of the functions present are automated.

The loop selection block of the music system receives biosignal data from the analysis block to set the music intensity level. Loop selection is more influenced by GSR changes than heart rate changes due to the smaller window size used to calculate the mean GSR. The GSR baseline value is subtracted from the current GSR mean value, assigned to the variable “GSRdiff,” and displayed in the graphical user interface. Heart rate mean values are tested against four heart rate ranges and a value is assigned to the variable “BVPbias” based on that range. The two variables “GSRdiff” and “BVPbias” are added together and this value is used to set the music intensity level to play at the next loop point. As mean GSR and heart rate values increase, music intensity also increases. The intent of this implementation is to reinforce player arousal levels with a corresponding change in music intensity. Music playback continues to loop until biosignal analysis or sensor input is stopped. The graphical user interface also includes a clock object to allow the tester to track elapsed time during each play test.

PLAY TESTS

Several of the research projects listed in the Background chapter have shown that biosignals make viable controls of game play and design features. In order to evaluate the effectiveness of the Bioreader music system design, the system was tested with four distinct game types. The games selected for this demonstration are the action adventure game *Prince of Persi*a (Ubisoft 2008), the puzzle game *Tetris Worlds* (Radical Entertainment 2001), the racing game *F-Zero GX* (Amusement Vision 2003), and the shoot ‘em up game *Gradius ReBirth* (M2 2009). Figures 24-27 show game play screen shots from each game tested. *Prince of Persia* was tested on a desktop computer with keyboard and mouse controls and orchestral music. All other games were tested on a Nintendo Wii using a Gamecube controller and techno music. Each title was tested 3 times. Play test duration was not strictly regulated to allow for natural game play. Tests were a minimum of 10 minutes and did not exceed 60 minutes.

Figure 24: *Prince of Persia* screen shot (Ubisoft 2008)

Figure 25: *Tetris Worlds* screen shot (Radical Entertainment 2001)

Figure 26: *F-Zero GX* screen shot (Amusement Vision 2003)

Figure 27: *Gradius ReBirth* screen shot (M2 2009)

Chapter 4: Results

The sensors and biofeedback software used in this project were designed and built specifically for the application of testing the viability of biosignals as a control input for game music. Much was learned through the process of building, debugging, and testing the entire biofeedback system from sensors to software. The following are the results and some observations from the development process.

The GSR Sensor

As noted in the Methods chapter, the GSR sensor went through one revision. While the aluminum foil electrodes made the sensor straps easy to attach and the form-fitting factor appeared desirable, the poor signal quality measured with this prototype made the material unsuitable. The non-porous quality of foil caused sweat to accumulate at the contact site, limiting the amount of time the sensor could be worn. Also, it was felt that the electrodes would deteriorate quickly. The O-ring electrodes were found to be more robust. The straps were made slightly more rigid by the O-rings, but it was still possible to make good contact at the test site and achieve an acceptable signal level.

Movement artifacts can be an issue when collecting galvanic skin response data, as noted in the Background chapter. This project confirms that observation. With the electrodes attached to the ring and small finger, care had to be taken during play tests not to move the electrodes. Movement was observed causing sudden drops in GSR signal level, followed by a sudden return to the previous level. If the movement was severe enough, the sensor might be re-seated, causing the measured skin conductance level to change. This problem was observed with the game pad controller, mostly caused by shifting grip, but can be prevented by maintaining a relaxed grip. Refer to Figure 28 for an example of GSR movement artifacts.

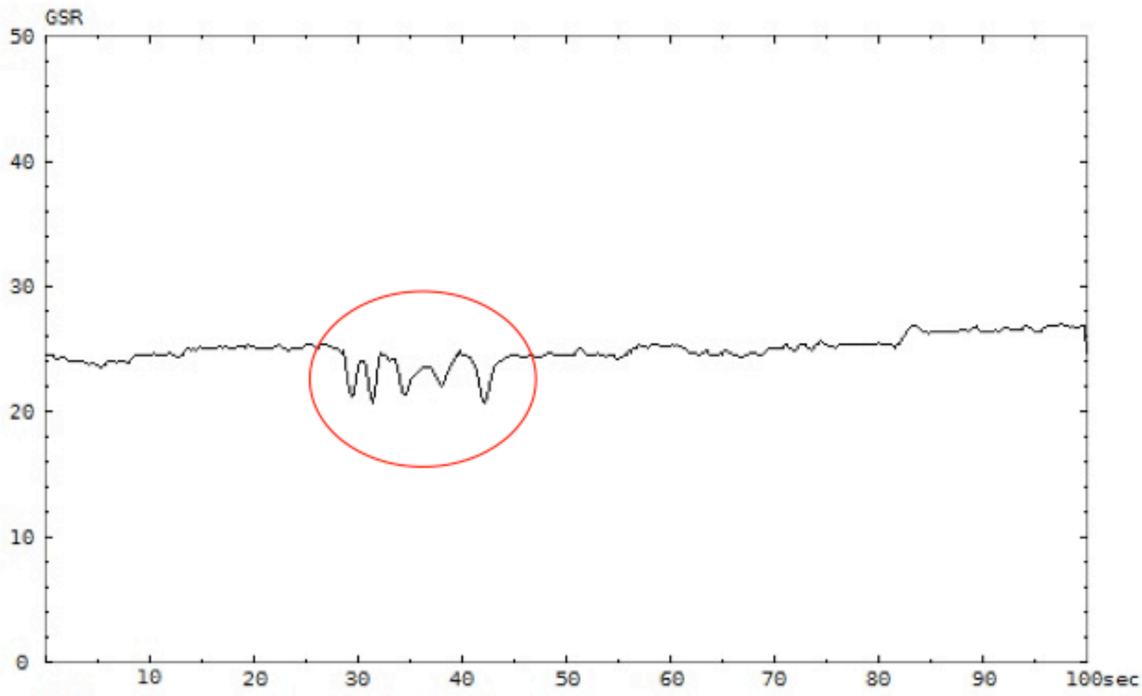

Figure 28: GSR signal with movement artifacts between 30-45 seconds

Movement artifacts were slightly more difficult to avoid with the keyboard controller. The finger strap sensor design was the best choice for testing with a keyboard-controlled game. A GSR sensor that clips on to the end of the finger similar to the Wild Divine sensor shown in the Background chapter would be unsuitable in this situation. *Prince of Persia* requires the left hand for the standard keyboard directional controls WASD, as well as the E and R keys for special attacks and the space bar for jumps, as seen in Figure 29. It is not uncommon for computer games with keyboard input to require the use of all fingers of the left hand, covering the entire range of the keyboard from the function keys at the top to the Control key at the bottom. This presents a larger problem and some movement artifacts could not be avoided. The use of signal filtering and averaging discussed in the Methods chapter helped reduce the impact of movement artifacts, but not enough that SCR events could be reliably detected.

Fortunately, the music system use of the GSR signal does not rely on detecting SCR events.

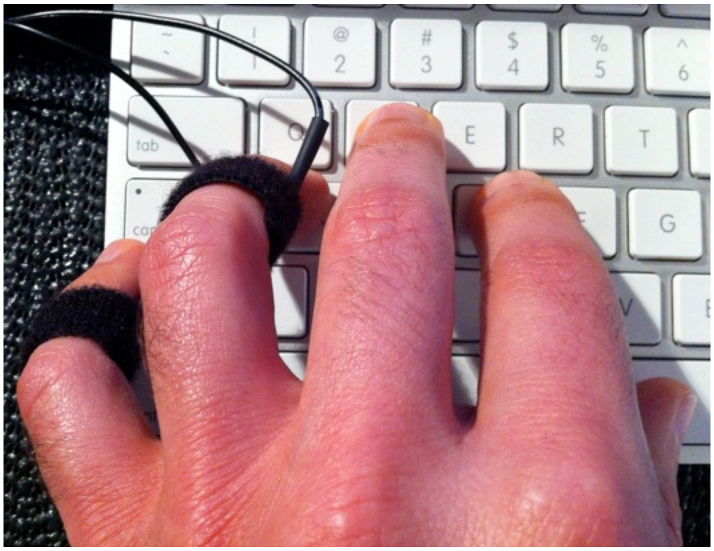

Figure 29: GSR sensor used with WASD keyboard controls

THE BVP SENSOR

Once the ear clip design was selected for this project, the BVP sensor was relatively simple to build. No problems were encountered during construction of the sensor, but some problems arose during testing. Movement artifacts are a known problem when using BVP sensors and this project confirms that issue. Slight movements during testing resulted in signal distortion that could interfere with heart beat event detection, as seen in Figure 30. Keeping the head stationary during play tests was found to be the best solution for minimizing artifacts. A BVP finger clip sensor would have required the hand to be immobilized and would have been impractical.

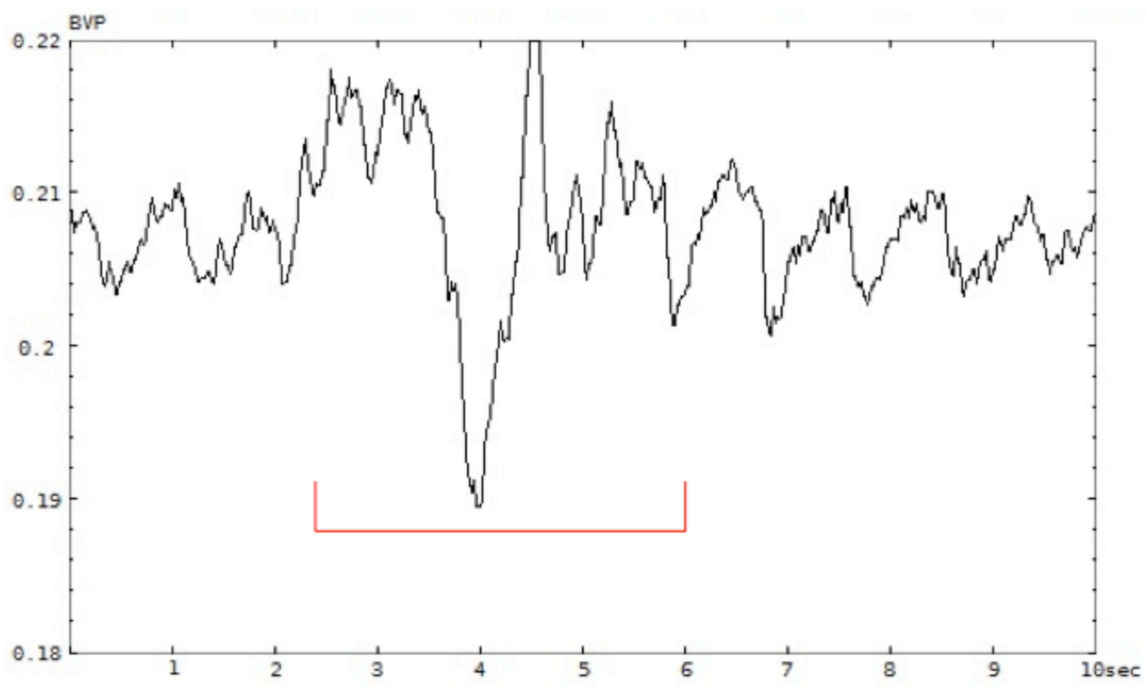

Figure 30: BVP signal with movement artifacts between 2-6 seconds

Placing the BVP sensor properly was also troublesome. Using the BVP signal display graph as feedback, it was found that multiple placement attempts were necessary to obtain a useable signal during most test sessions. It was also found that once the sensor was properly placed, the signal contained excessive jitter for the first 1-2 minutes of measurement, as seen in Figure 31, making initial event detection more difficult. Compare this graph to the steady signal obtained minutes later, seen in Figure 32. The BVP sensor clip was also found to be extremely uncomfortable through extended periods of game play. After 10-15 minutes, there was noticeable discomfort that could be tolerated for up to 1 hour.

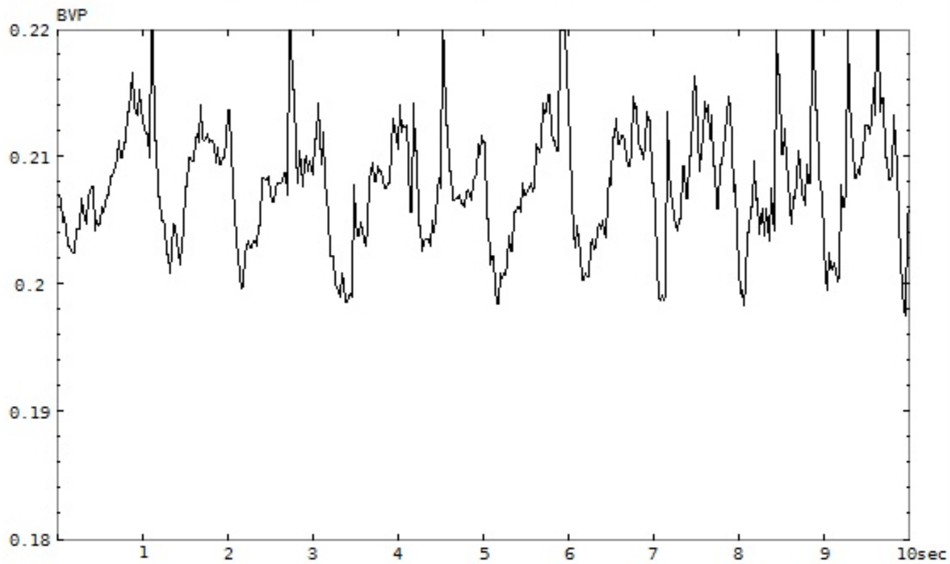

Figure 31: BVP signal with jitter immediately after placement

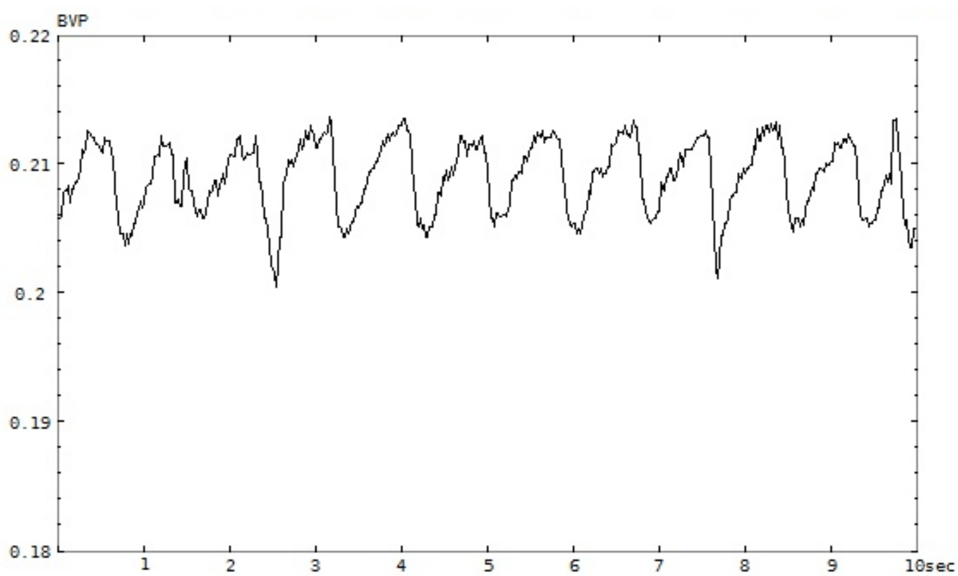

Figure 32: Steady BVP signal

SIGNAL PROCESSING

The impact of movement artifacts and other noise in both biosignal inputs was mitigated with digital signal processing. As mentioned in the Methods chapter, several filters were added to the Bioreader software to deal with noise that was present in the signal after analog to digital conversion. Figure 33 shows graphs of both signals without digital signal processing. The amount of noise in the GSR signal appears minimal, but a filtered signal would result in more accurate figures from the analysis block. The unprocessed BVP signal was more problematic. A periodic shape is visible in the signal, but in order for the event detection algorithm to work properly the noise needed to be minimized.

The first filter implemented was a simple low pass filter as the [LPF8] object, which removed an acceptable amount of noise in both signals, as seen in Figure 34. The noise spikes are no longer present in the GSR signal while some amount of detail is preserved. This balance was found to be acceptable and the low pass filter was selected to process the GSR signal during play tests. The BVP signal was smoothed significantly by [LPF8], but the peak-to-peak range was slightly reduced. This did not allow for enough distance between the upper and lower event detection thresholds and caused the event detection algorithm to report an excessive number of false heart beat events.

A weighted filter was implemented as the [weightAvgFilter] object. Control of this filter is handled by setting the weight value. Low value weights average in favor of previous values, smoothing the signal, and high value weights average in favor of the current input value, causing less smoothing. With the proper setting, this filter removes sufficient noise, while leaving some amount of detail in the signal. The peak-to-peak range can be slightly larger, and the peaks more defined. This made heart beat event detection easier, and the weighted averaging filter was chosen to process the BVP signal. The optimal weighting factor was found to be 0.25, as seen in Figure 35.

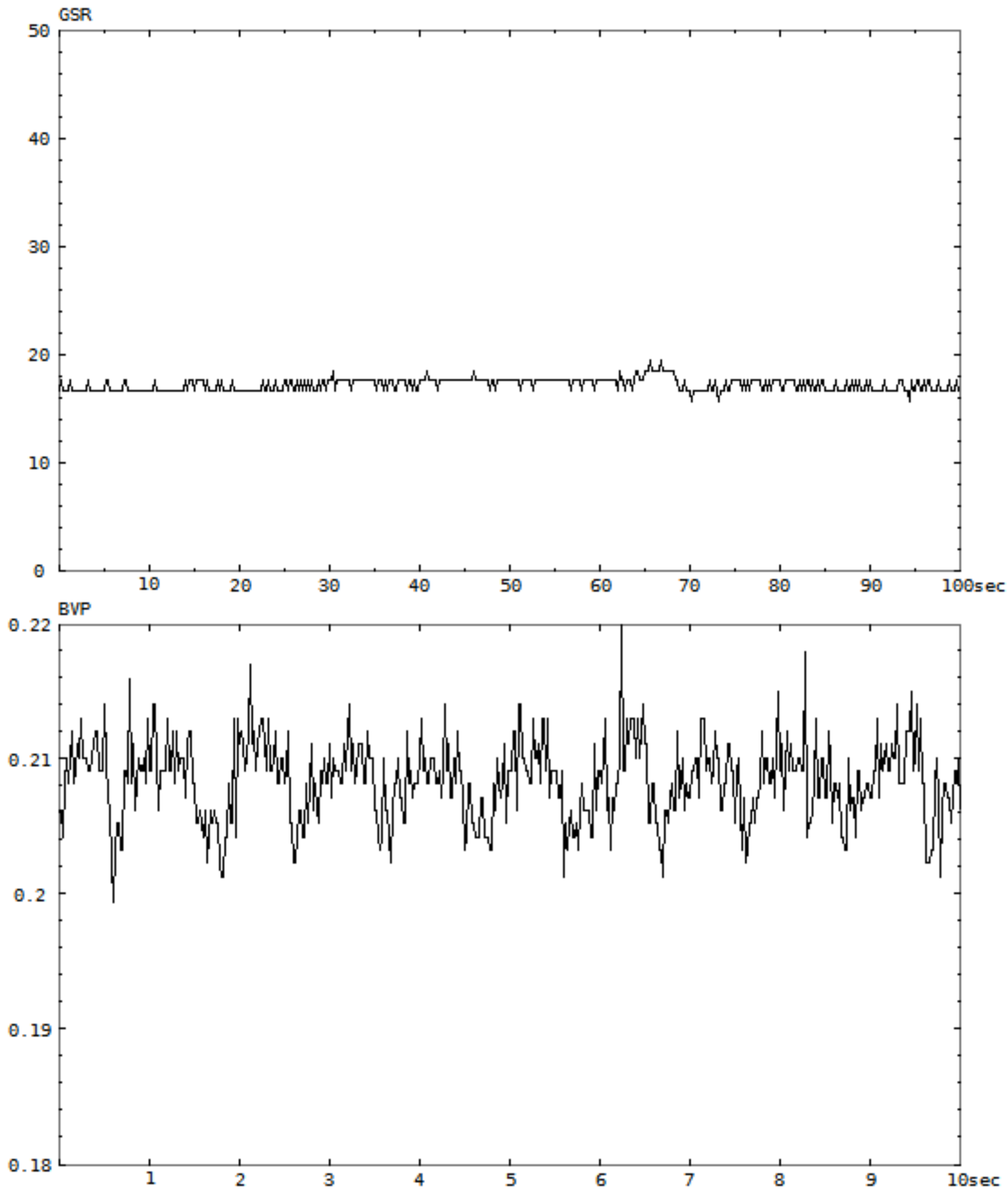

Figure 33: GSR and BVP signals with no filtering

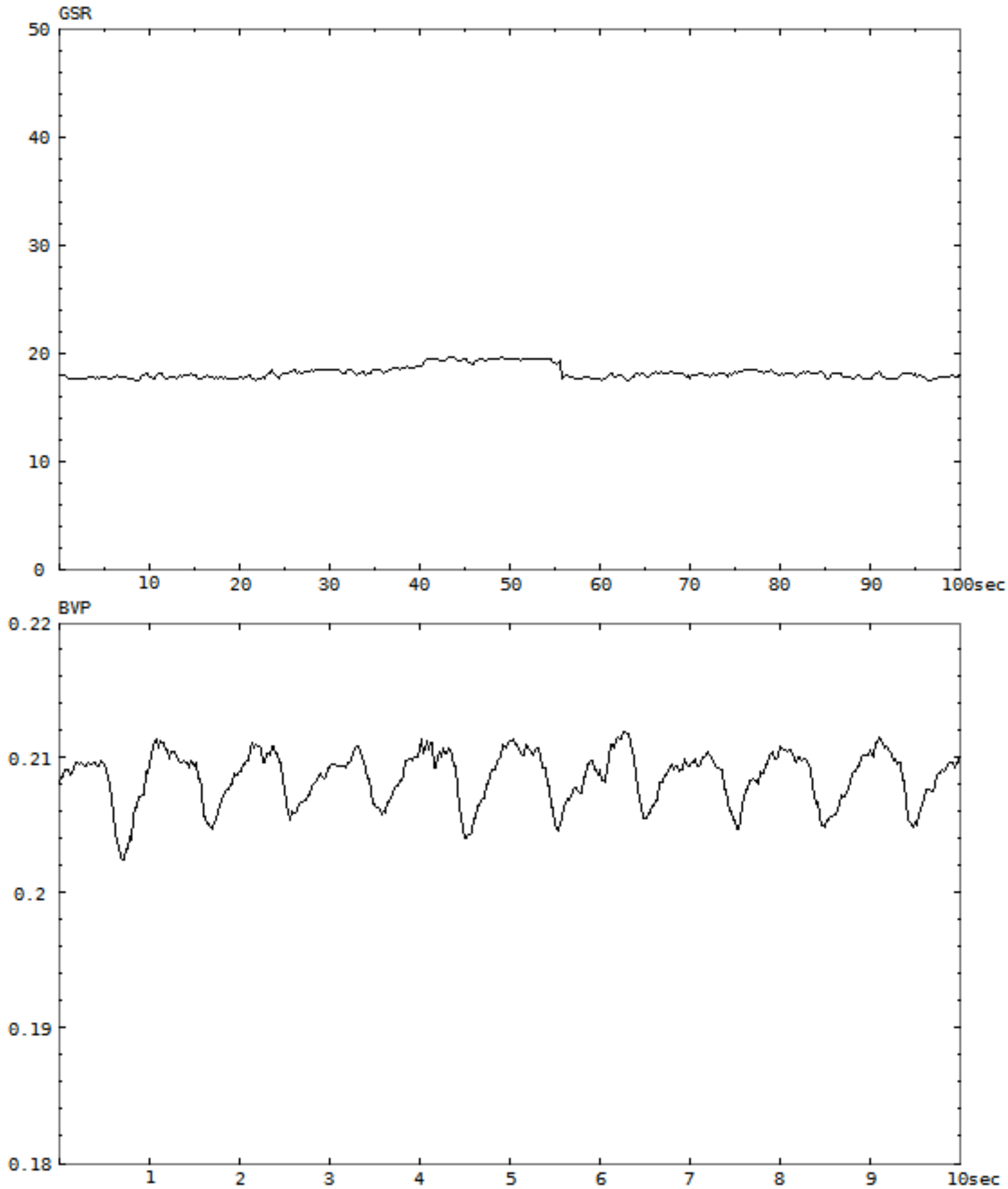

Figure 34: GSR and BVP signals with low pass filtering

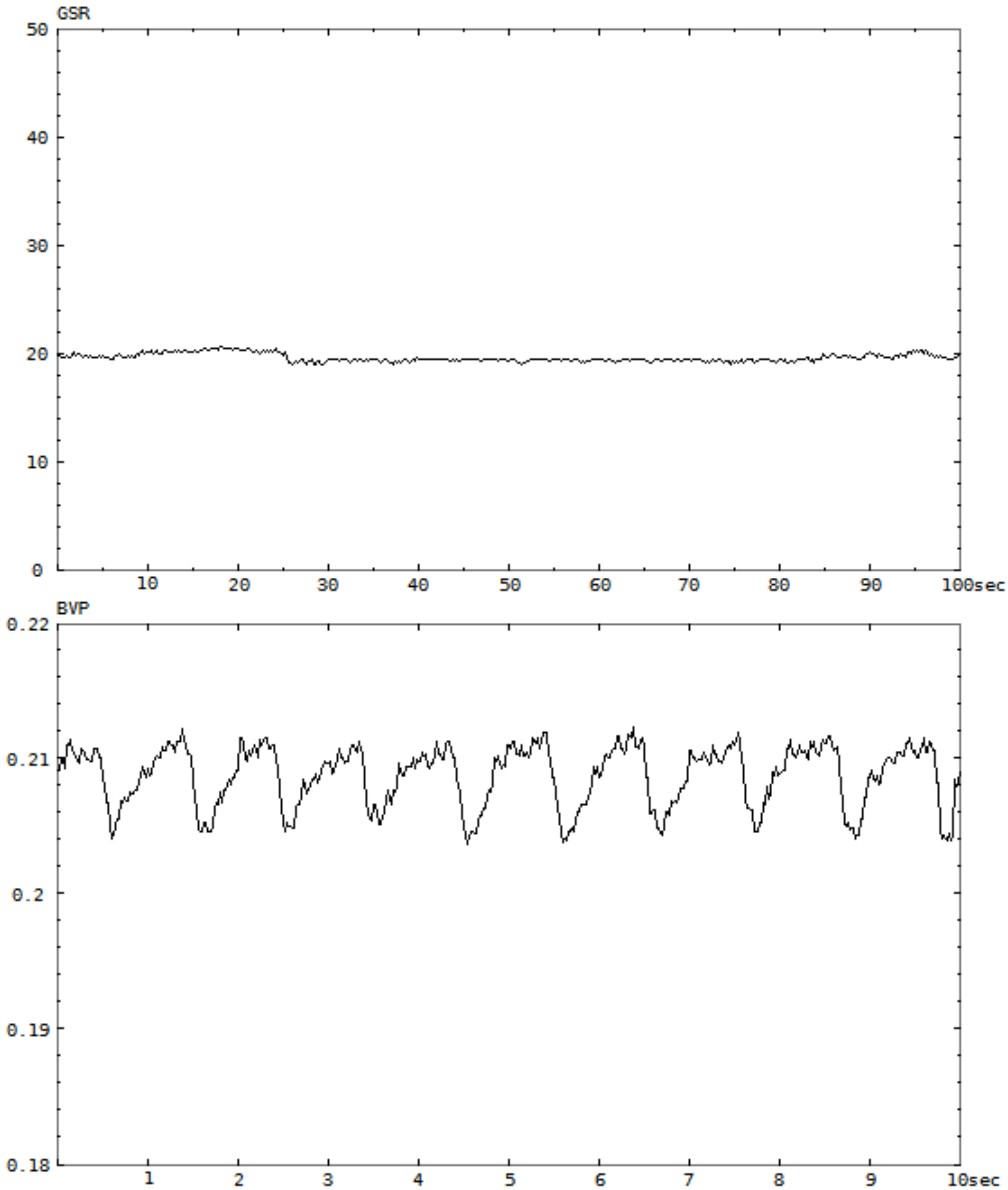

Figure 35: GSR and BVP signals with weighted averaging filter

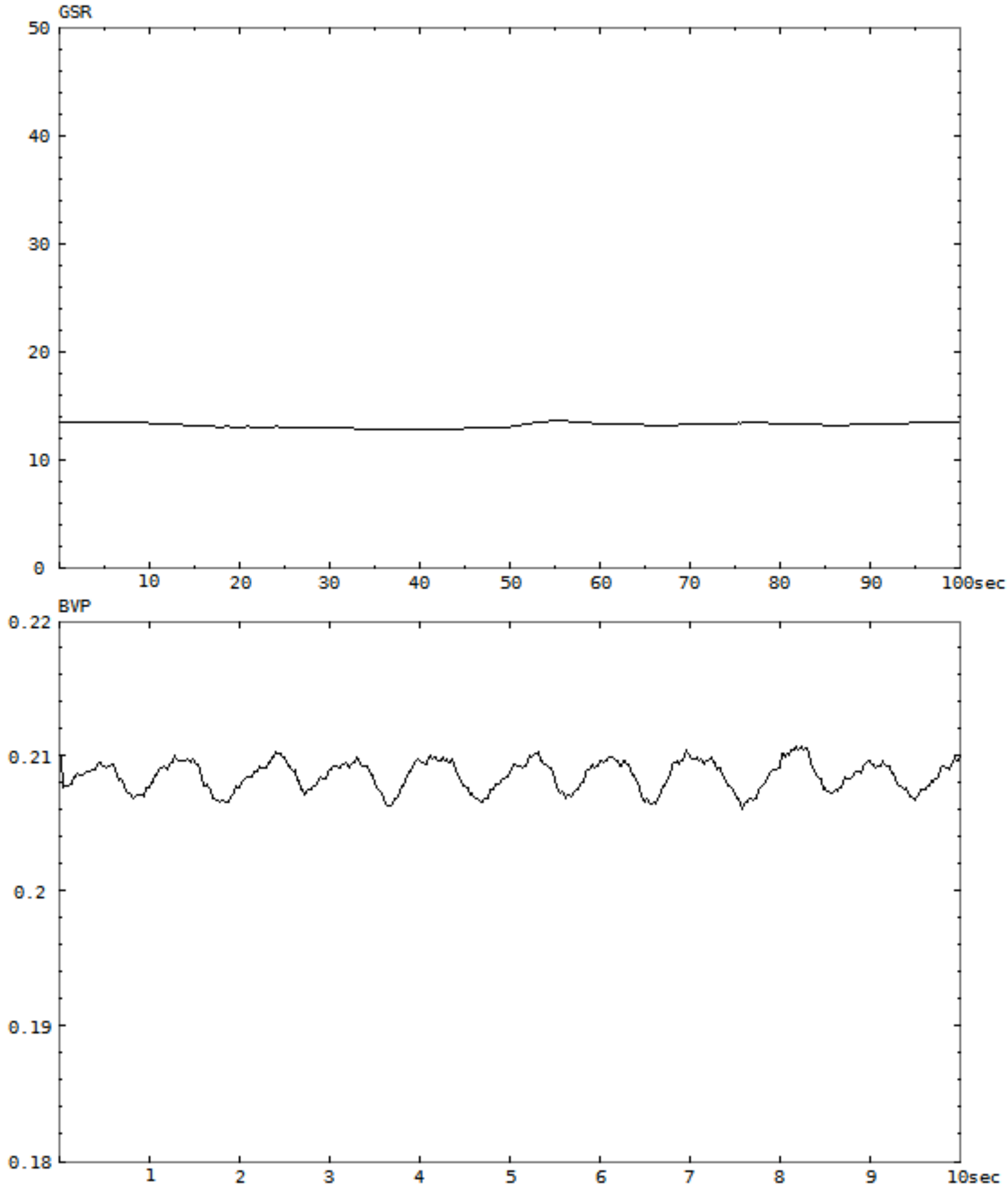

Figure 36: GSR and BVP signals filtered with averaging array

The final filter tested was an averaging array in the [arrayAvg] object. This filter behaves similarly to the low pass filter, with a more severe cutoff, as seen in Figure 36. The GSR signal is smoothed the point of being almost featureless. The peak-to-peak range of the BVP signal has been decreased significantly and the peaks have lost much definition, making threshold based heart beat event detection very difficult. Reducing the number of array elements to decrease signal smoothing made this filter almost indistinguishable from [LPF8]. The averaging array filter was not used during play tests.

Biosignal Data Analysis

The biosignal data generated by the analysis block is passed to the music system and also stored for later statistical analysis. This data consisted of the running mean and slope values for the analysis window of each biosignal. This data explains the motivation behind the final design of the Bioreader music system, as well as some of the quirks of how the system behaved during game play testing. It was decided during testing of the music system, prior to game play testing, that slope data from the [calcSlope] object would not be used to influence music intensity level. The slope data is still valuable for future considerations however. Refer to Appendix D for complete play test statistics and graphs.

The GSR signal data collected supports the findings of several research projects mentioned in the Background chapter. Baseline skin conductance levels vary over a wide range from day to day. This is reflected in the standard deviation of GSR values from all play tests. In general, the GSR curves recorded during each play test reflect changes in player arousal level over time, supporting other researchers' finding that this biosignal reflects affective state to some degree, and is a viable control input for game elements.

Overall, GSR levels tended to rise, as seen Figure 37, and which is also supported by the mostly positive running GSR slope figures. This could be explained as the player's response to in-game events. As the player progresses, each of the games tested tends to increase in difficulty, placing the player under more stress. However, the signal did vary in a way that shows a constantly changing state of arousal. While the overall trend was an increase in skin conductance levels, there are periods of relaxation. The player may habituate to certain stressors through repetition, or the design of the game allows for occasional recovery periods. In these cases, the GSR signal will decrease until the next stressor is reached.

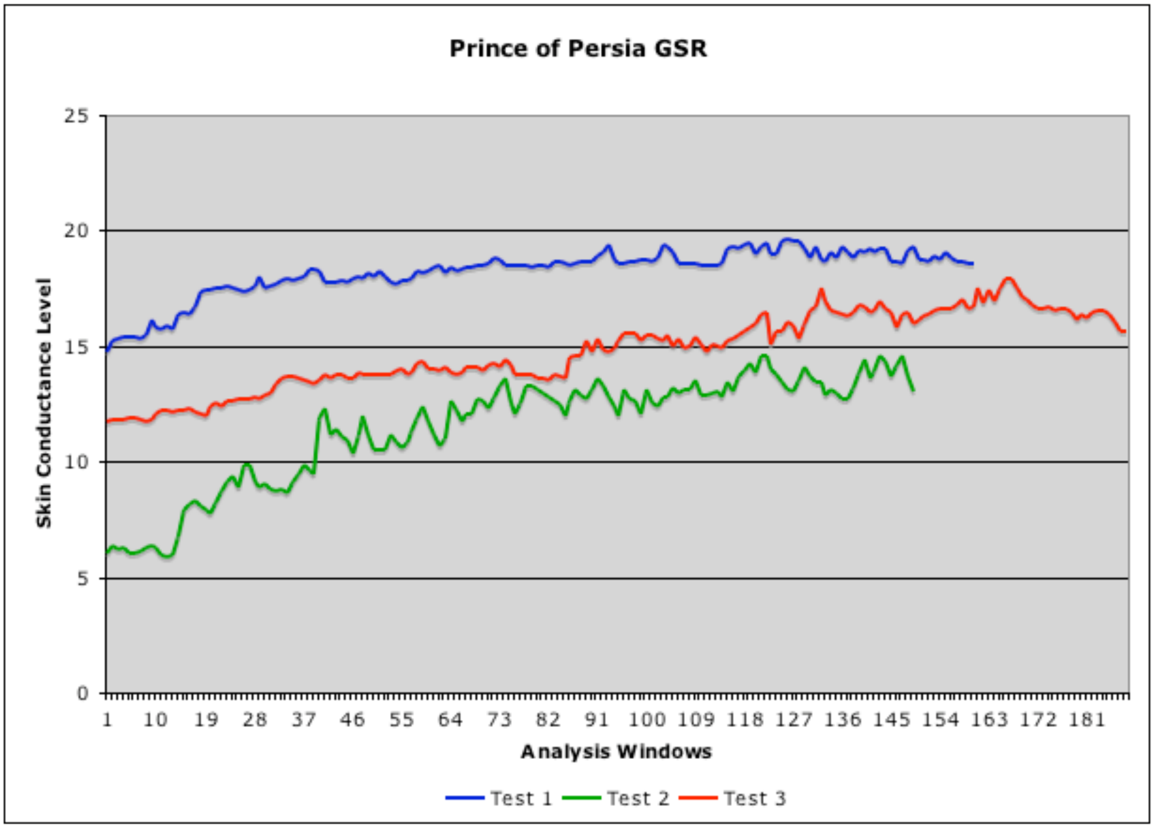

Figure 37: Example GSR plot

The BVP signal proved to be less useful as a control input. As noted in the previous chapter, movement artifacts were an issue. Analysis of the signal reveals a wide standard deviation that is most likely not the result of changes in the player's arousal level. Mean heart rate values tended to cluster around normal heart rates, but with oscillations well outside the range of a sitting heart rate, even for a person under perceived stress. This indicates a problem with the BVP signal analysis block. Possible reasons include a high number of movement artifacts, a fault with the heart beat event detection algorithm, or that the algorithm for calculating heart rate is flawed. Taking heart rate variability into account does not explain the wide variation in recorded heart rates. The two-minute time window was insufficient to smooth out artifacts in the BVP signal and running heart rate, but too long to allow for a timely response to game events. This relatively long analysis window, compared to the GSR analysis window, also resulted in a BVP data set that is too small to derive many meaningful conclusions.

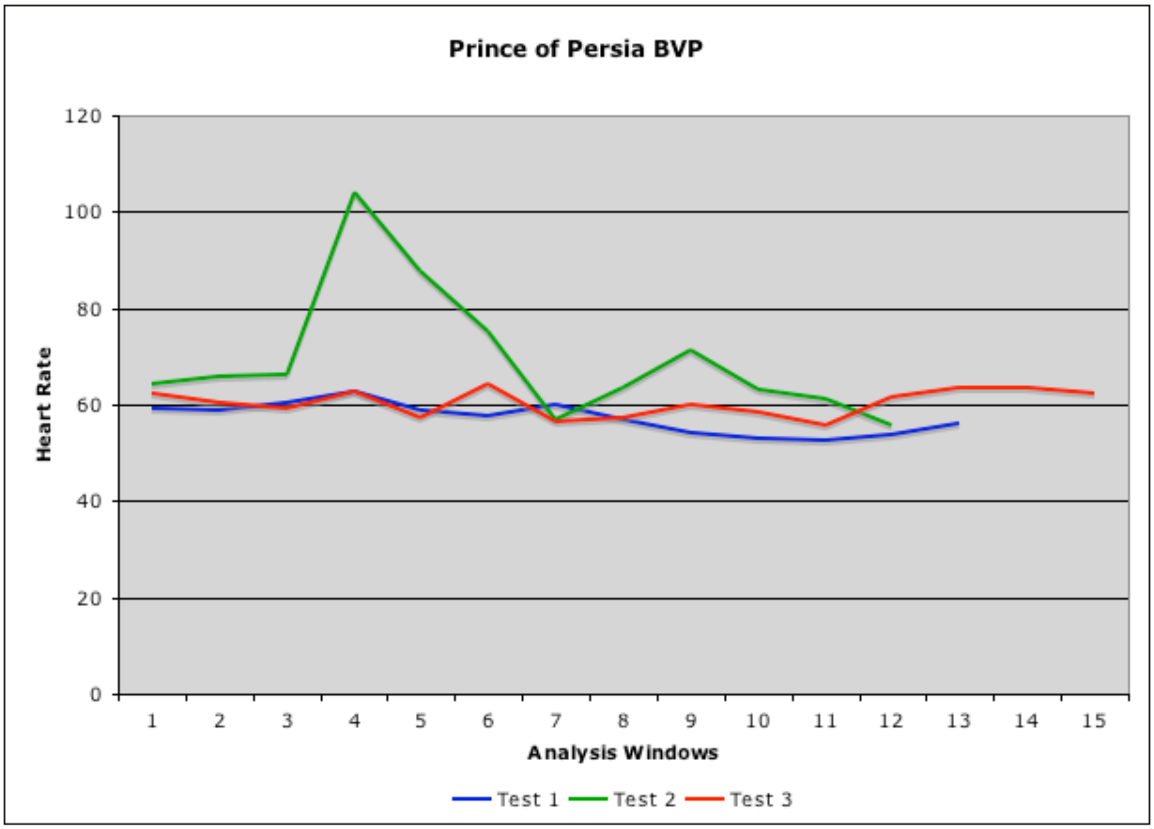

Figure 38: Example BVP plot

THE MUSIC SYSTEM

The Bioreader music system was designed to react to tonic changes in the biosignal inputs. The size of the analysis time windows coupled with the lag time of the music system means it is not capable of reacting to phasic changes properly. The system did react to overall player arousal and was able to highlight the player's affective state. Changes in music intensity level that were delayed by music system lag time were not noticeable, which was consistent with the findings of Sakurazawa et al. (2004). This is an advantage of reacting to tonic changes in affective state. The perception of the system's performance is not reliant on game event timing.

The initial prototype of the music system used slope instead of mean to drive changes in music intensity level. This implementation reacted to changes in arousal level derived from the biosignal inputs, but the result was not aesthetically pleasing. In this configuration, a change in music intensity level of any magnitude would be reflected for one loop cycle. If the player's arousal level went up quickly and stayed up for example, music intensity would jump from lowest intensity to highest for one loop cycle and then return to baseline. This disconnect between music intensity and a persisting state of arousal was found to be jarring, drawing the player out of the illusion of an immersive game space. The solution was to compare the current mean to the baseline level of each biosignal. This allowed music intensity level to remain roughly parallel to player arousal level.

Play tests revealed that the close pairing of music intensity and biosignal levels still felt unnatural at times. Data derived from the BVP signal was not valid and should have been ignored. The effect was minimized by the fact that the music system gives more weight to the influence of the GSR signal. However, player perception of arousal level can change in ways that are not always reflected in a single biosignal. GSR levels could stay elevated for a period of time that exceeds the period that the player may perceive as an elevated state of arousal.

Overall the music system behaved in a satisfactory manner, reinforcing the player's affective state with real time changes in music. Even though the performance of the system suffered from the inclusion of the BVP data stream, it was still demonstrated that tracking and reacting to player biosignals could augment the behavior of a game music system. Sensors gathered accurate data, but signal processing and the algorithm used to control changes in music could be improved. Suggestions for improving these areas and others are laid out in the next chapter.

Chapter 5: Discussion

BIOFEEDBACK SENSORS

The challenges encountered with biosensors in this project may partially explain why biofeedback applications have not appeared often in commercial games. In order to create viable commercial gaming biosensors, the design must be completely user-centered. Currently, most research projects implement a controller-centered design. What works in the laboratory most likely will not work in the home. For accurate biosignal readings, the sensors must be affordable, robust, non-invasive, and easy to use.

The availability of low cost wireless microcontrollers creates opportunities for developing better, easier to use game-specific biosensors. The ability to obtain GSR and BVP readings through the hand means sensor systems could be incorporated into existing game controllers. New input devices such as Microsoft's Kinect camera system and the Peregrine gaming glove shown in Figure 39 are just some of the ways biosignal input could be added to video game systems in a more user-centered design (Iron Will Innovations 2012).

Figure 39: The Peregrine glove controller (Iron Will Innovations 2012)

BIOFEEDBACK IMPLEMENTATION

A biofeedback system for games must be simple and flexible. Biosignals and affective states are not as concrete as push button interfaces. Affective systems must be comprehensive enough to handle this variance. Baseline inputs will differ from user to user, as will reactions to game events. The software system must be designed to handle a wide range of inputs. Detecting a user's baseline biosignals and calibration could be built into game design. Game players are accustomed to learning game controls and features during introductory tutorial levels. There is an opportunity here for the game designer to also get accustomed to the player. Not every game play session starts off from the beginning of a game however. Affective game system designers would need to devise other ways to establish the player's baseline biosignals and adapt to constantly changing conditions.

Coarse biofeedback is possible, but these systems are far from perfect. Future development of video game biofeedback must answer several questions. How are errors to be handled? What constitutes and acceptable margin of error? Fortunately, in a video game application, an error in a biofeedback system is not as detrimental is it could be in a medical application. If an error is detected in a game biofeedback system, the data may simply be ignored momentarily. Biosignal input is not the only control input. A game music system typically reacts to player actions such as defeating a boss, or game events such as entering combat mode. The inclusion of biosignal input, even in a minimal way, could enhance the immersive experience.

FUTURE WORK

Establishing the connection between biosignals and game design elements is the first step towards building affective game systems. The work encompasses several disciplines and will require more research before implementations can move beyond novelty. The following suggestions for future work will help develop ideas for improving player experience through more immersive environments.

The functioning of a biofeedback system is greatly improved by using multimodal inputs (Zeng et al. 2009). Incorporating multiple inputs allows for better assessment of affective states that are not expressed through only one biosignal. This will require the development of better sensors and affect recognition methods. More testing will be necessary to learn best practices for mapping biosignal data to game music and other game parameters. More research is necessary to develop game systems that correlate game event data with biosignal data. This could greatly improve the perceived impact of even the simplest biofeedback system. Implementations will depend on several factors, including genre, audience, game design, and the desired effect on the part of the developer. A system that knows both what a player is doing and how the player reacts to choices and game events will allow designers to make better decisions regarding how to use biosignal input.

Appendix A: Circuit Diagrams

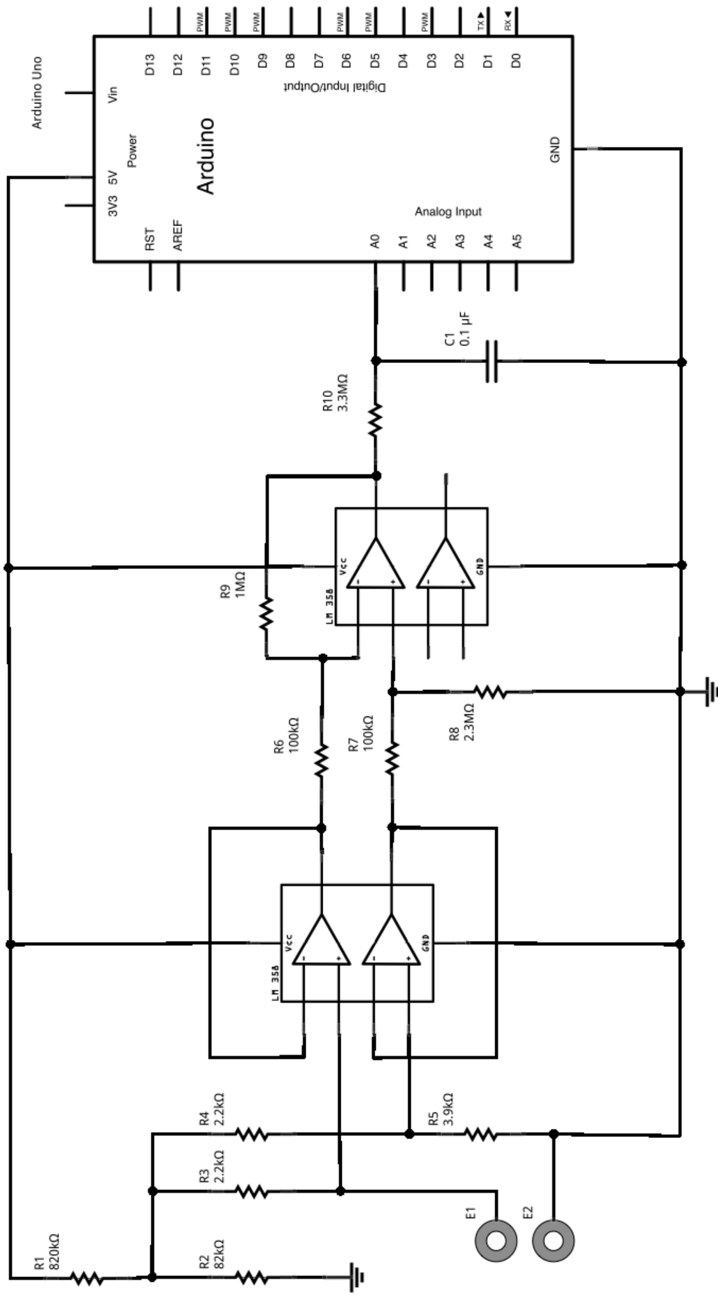

Figure 40: GSR circuit

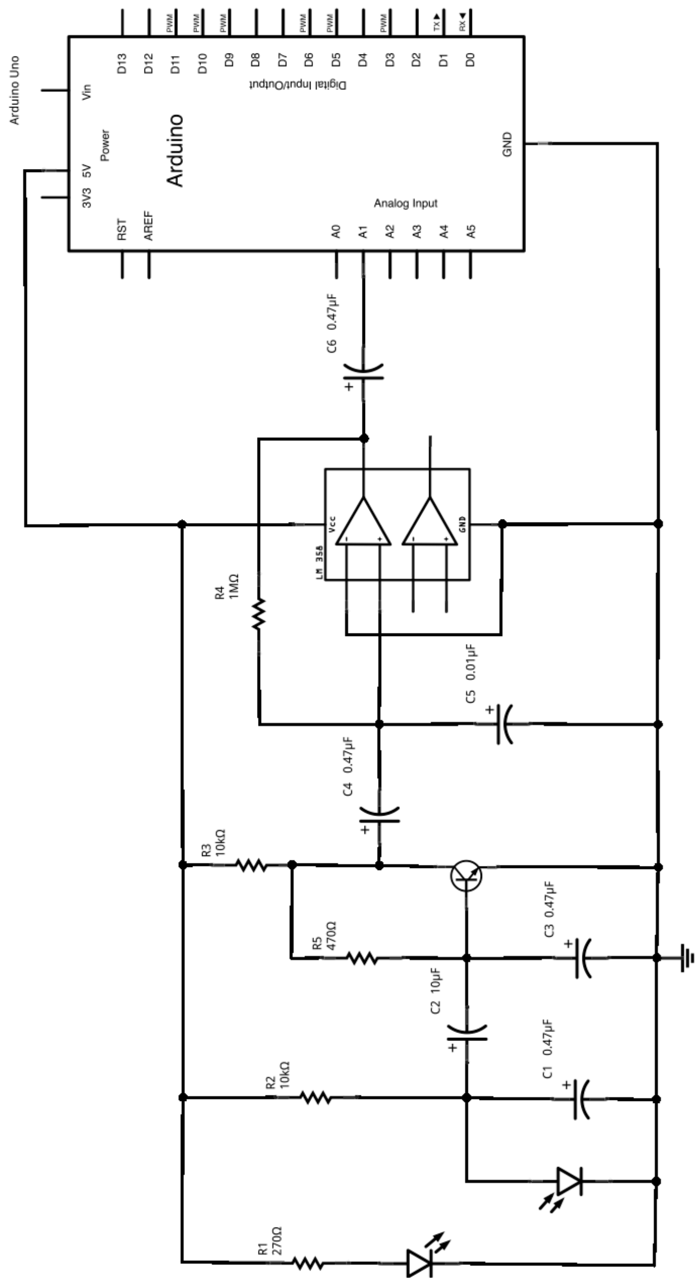

Figure 41: BVP circuit

Appendix B: Parts Lists

GSR Circuit

Resistors

R1	820k
R2	82k
R3	2.2k
R4	2.2k
R5	3.9k
R6	100k
R7	100k
R8	2.3M
R9	1M
R10	3.3M

Capacitors

C1	0.1μF ceramic

Semiconductors

U1	LM 358 dual op-amp
U2	LM 358 dual op-amp

Sensors

E1	electrode, steel washer
E2	electrode, steel washer

BVP Circuit Parts List

Resistors

R1	270Ω
R2	10k
R3	10k
R4	1M
R5	470Ω

Capacitors

C1	0.47 μF electrolytic
C2	10 μF electrolytic
C3	0.47 μF electrolytic
C4	0.47 μF electrolytic
C5	0.01 μF ceramic
C6	0.47 μF electrolytic

Semiconductors

LED1	SFH487P infrared LED
P1	SFH309P photodiode
Q1	2N3391 NPN
U1	LM 358 dual op-amp

Appendix C: The Bioreader Music System

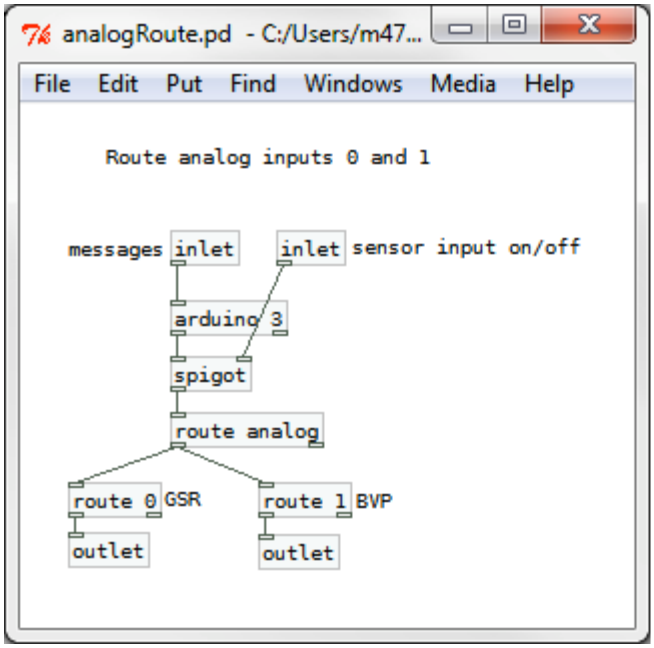

Figure 42: [analogRoute] routes by signal type and port

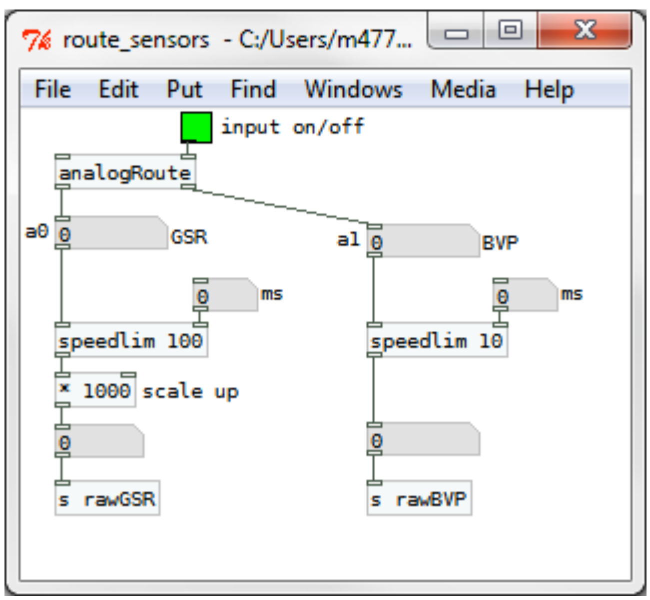

Figure 43: [route_sensors] monitors inputs, resamples and scales signals

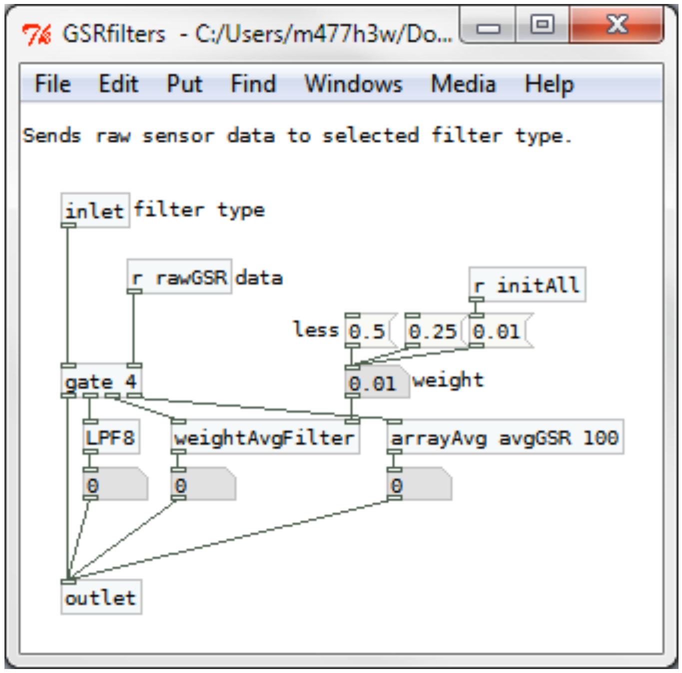

Figure 44: [GSRfilters] subpatch, duplicated as [BVPfilters] with appropriate inputs

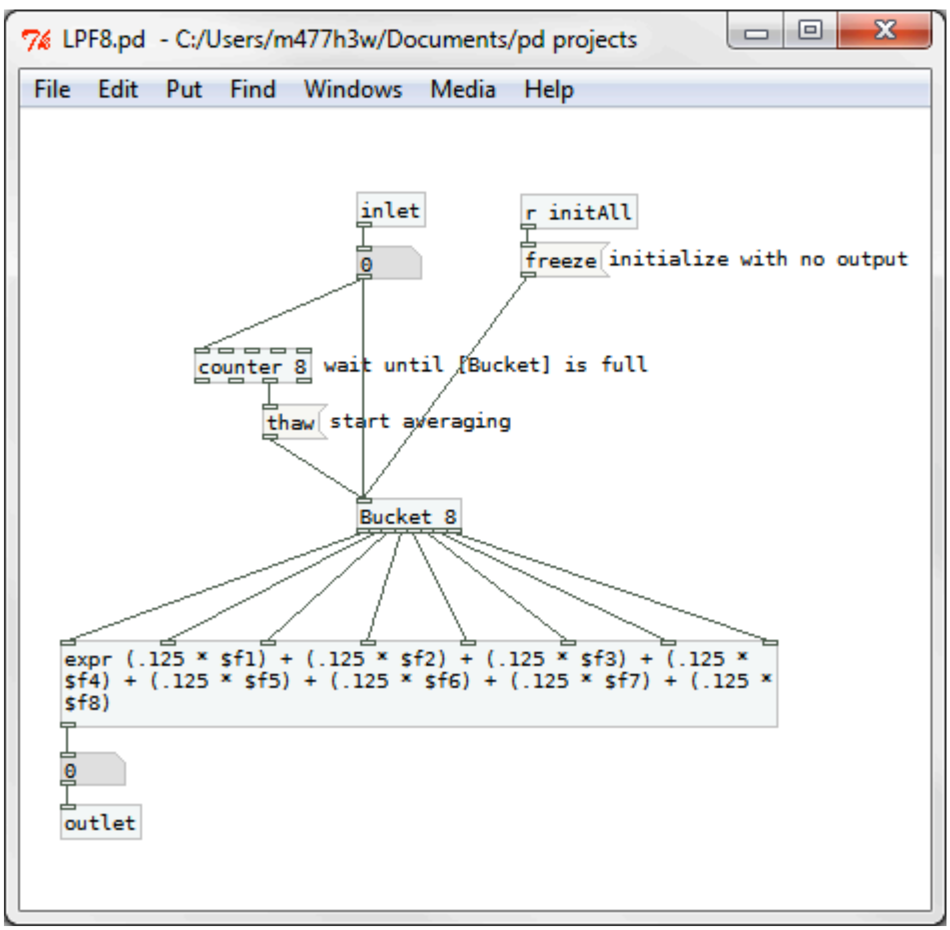

Figure 45: [LPF8] simple FIR filter

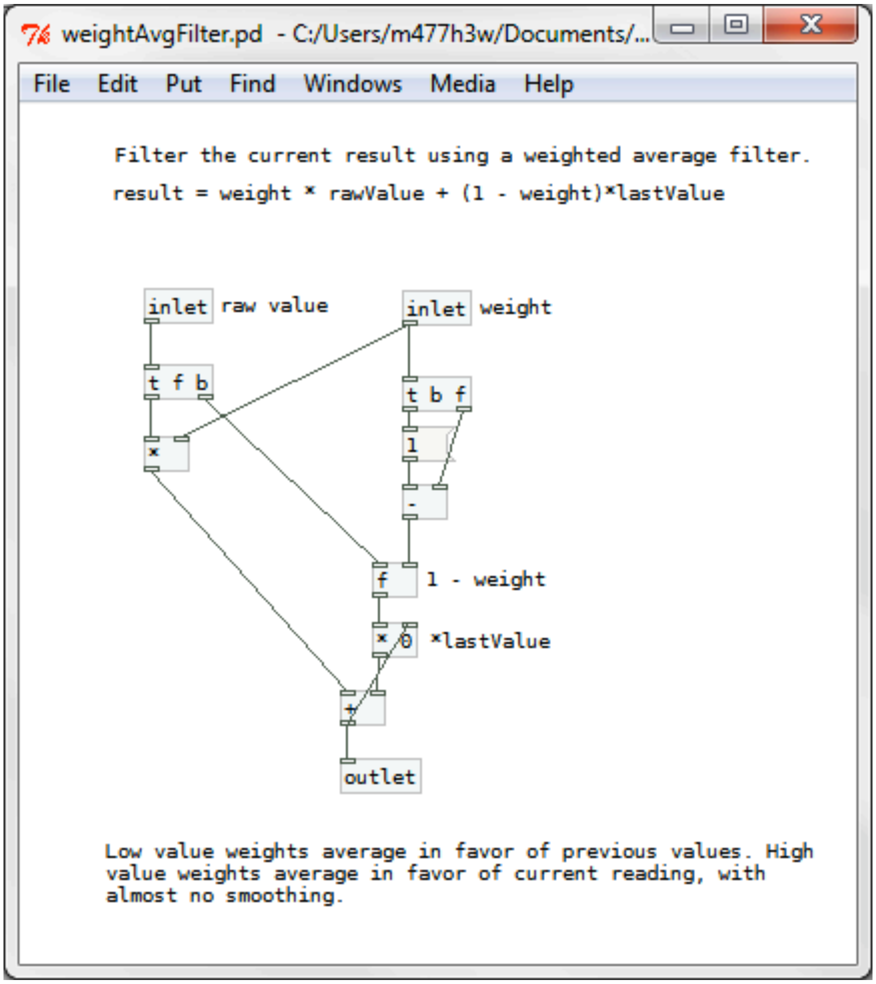

Figure 46: [weightAvgFilter] weighted average filter

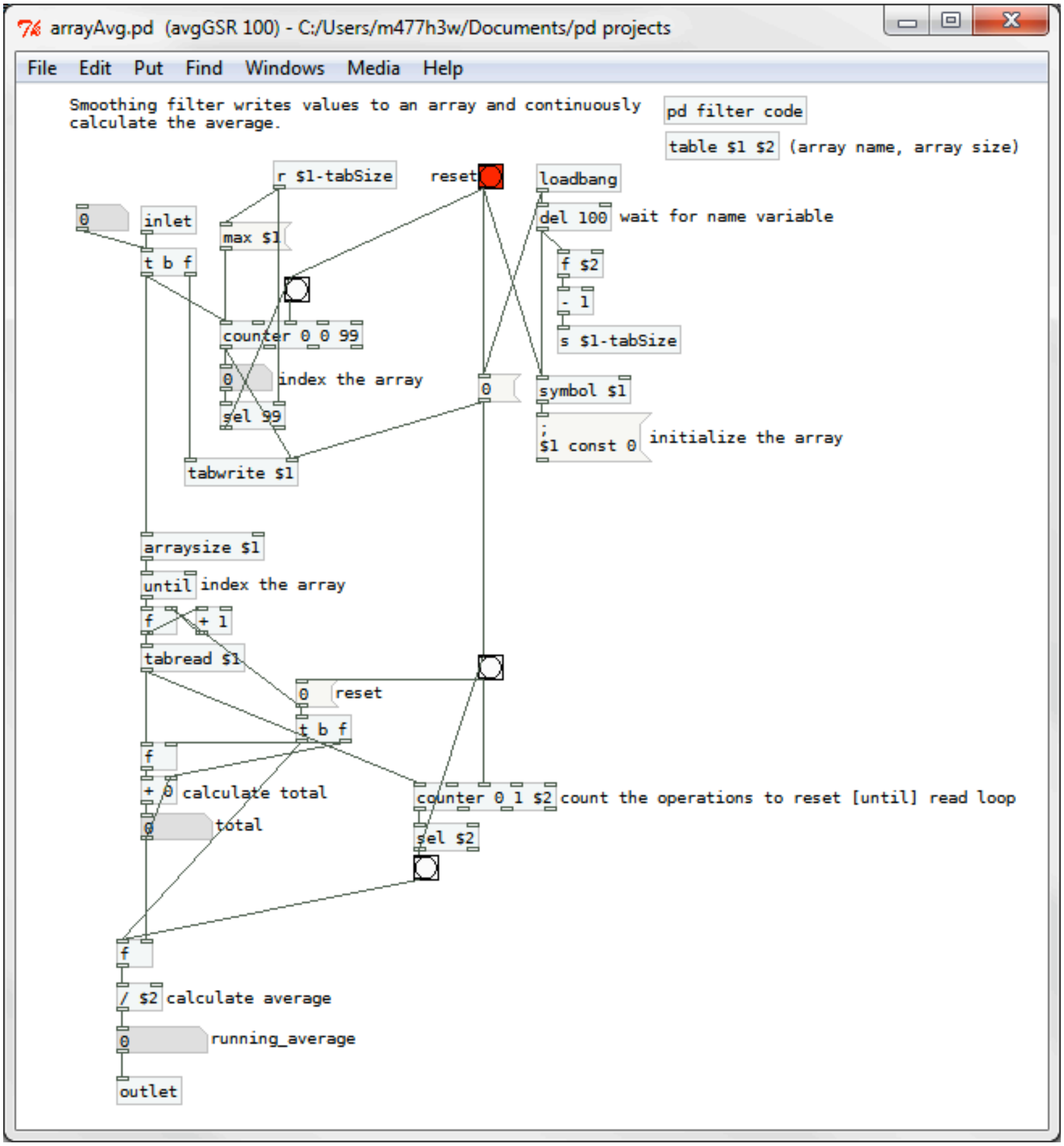

Figure 47: [arrayAvg] smoothing filter using 100 element array

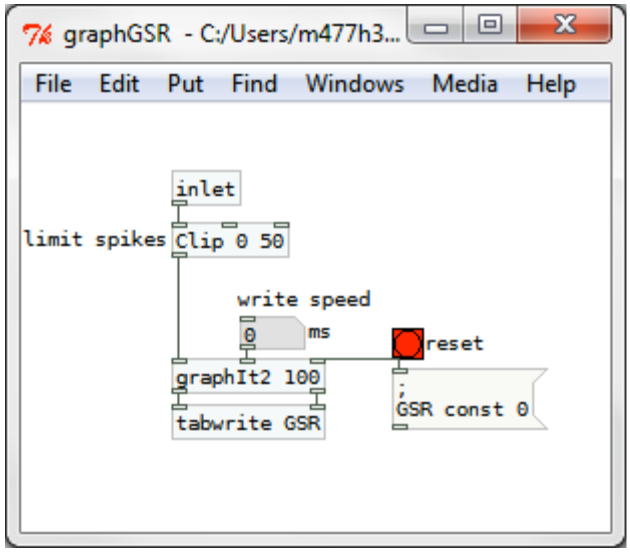

Figure 48: [graphGSR] subpatch, duplicated as [graphBVP] with appropriate variables

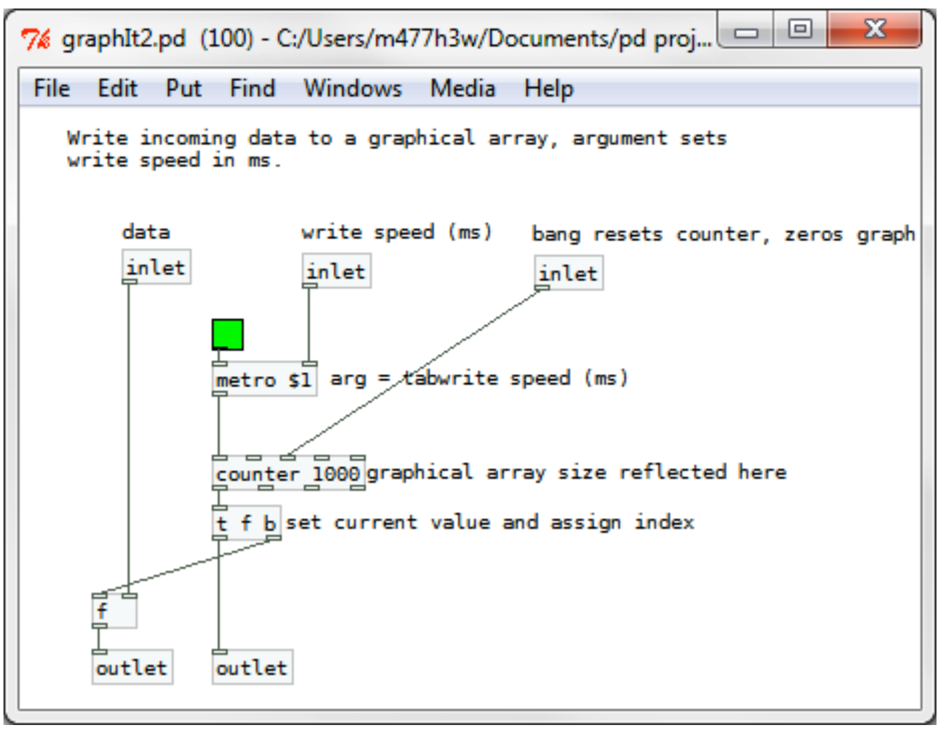

Figure 49: [graphIt2] writes inputs to graph display

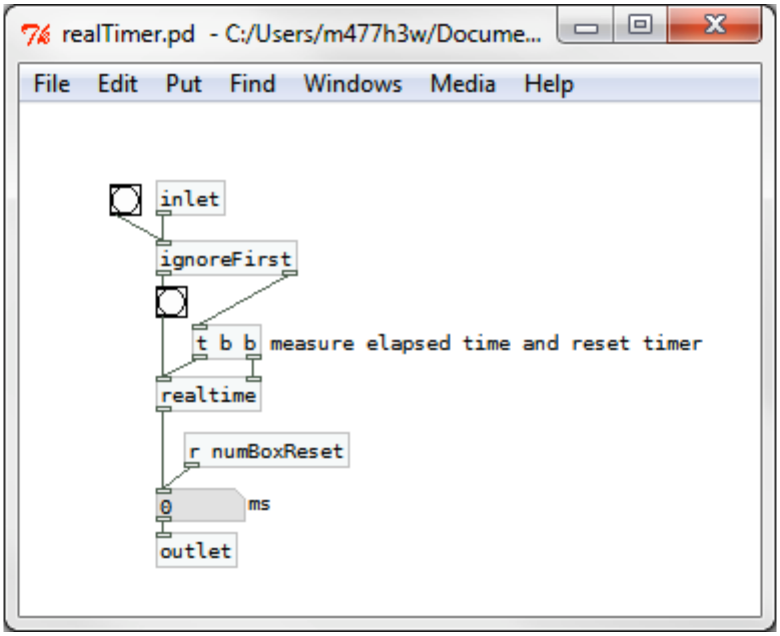

Figure 50: [realTimer] measures elapsed time between consecutive events

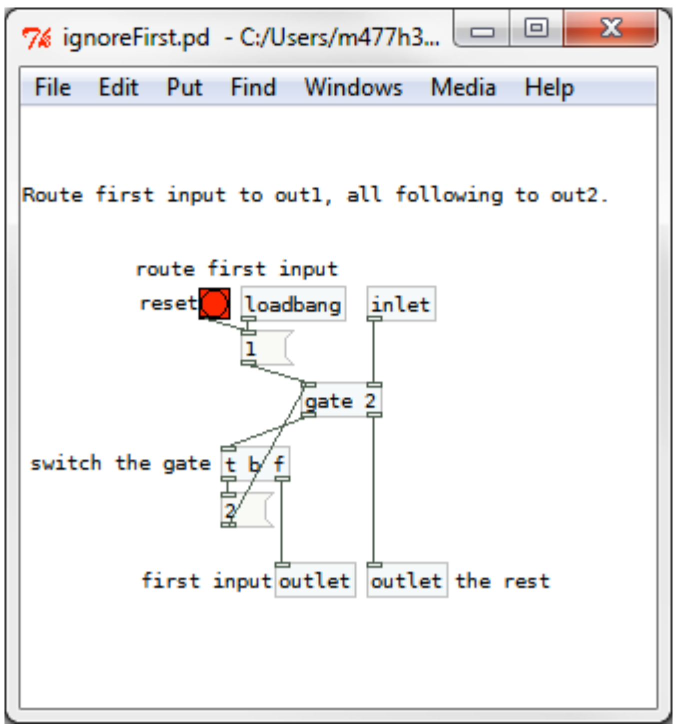

Figure 51: [ignoreFirst] routes inputs to appropriate outputs

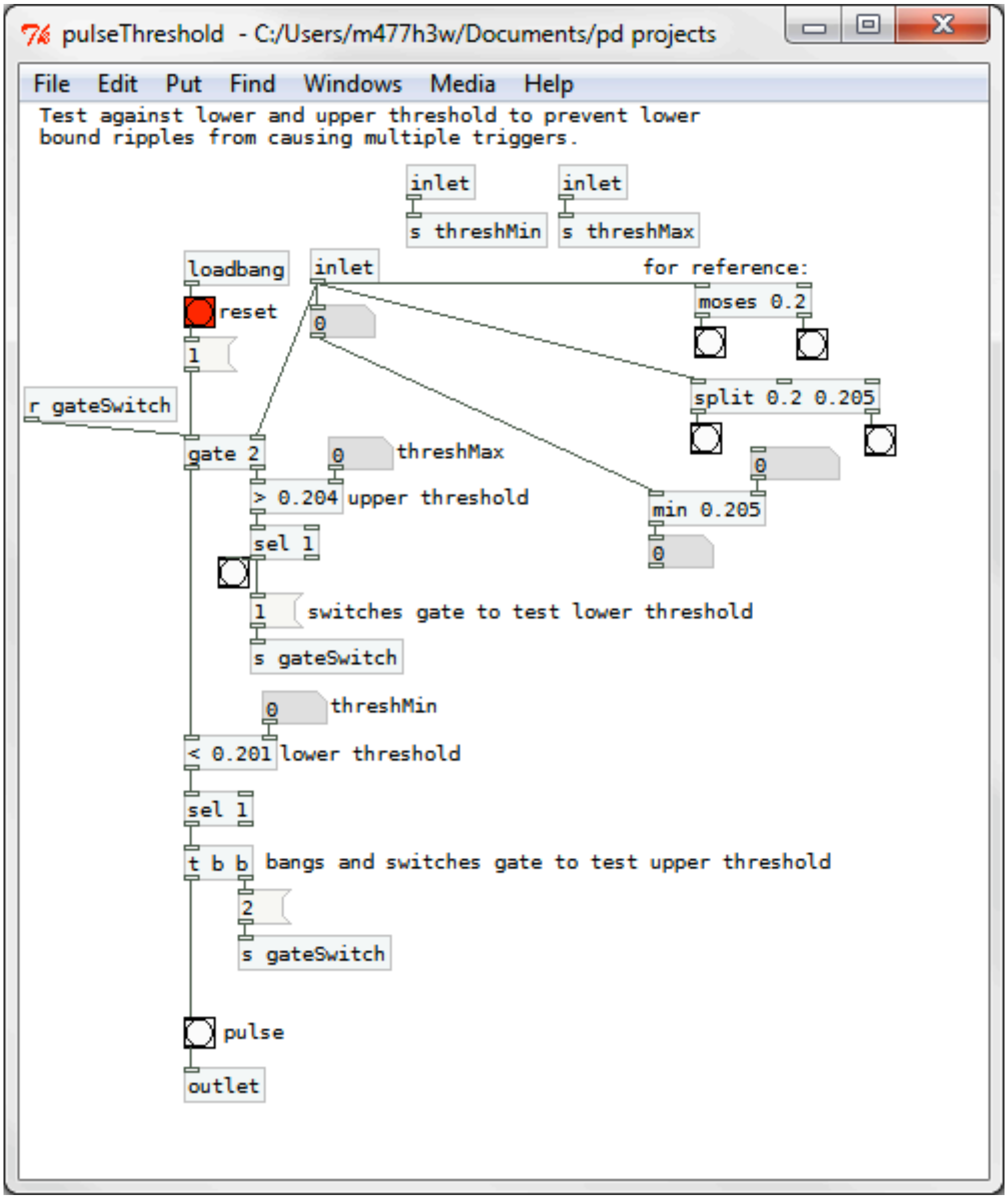

Figure 52: [pulseThreshold] tests input signal against upper and lower thresholds for event detection

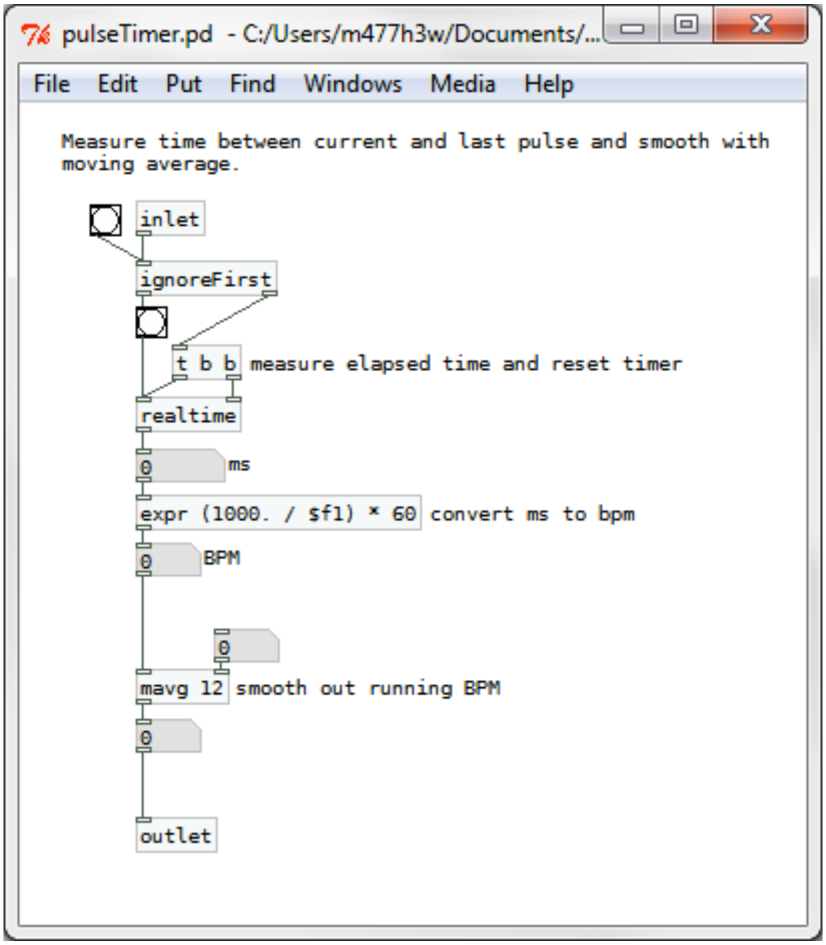

Figure 53: [pulseTImer] measures time between events, converts milliseconds to BPM, and smoothes data with a moving average filter

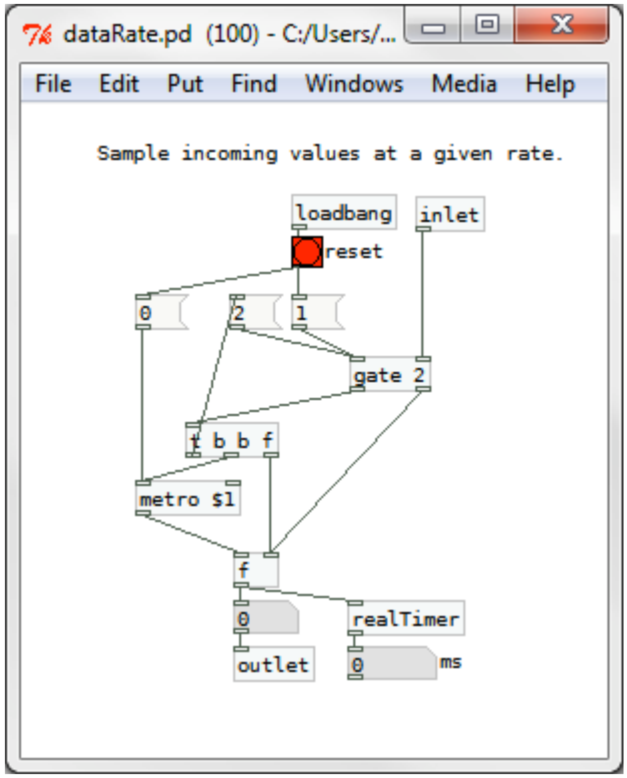

Figure 54: [dataRate] upsamples incoming signal

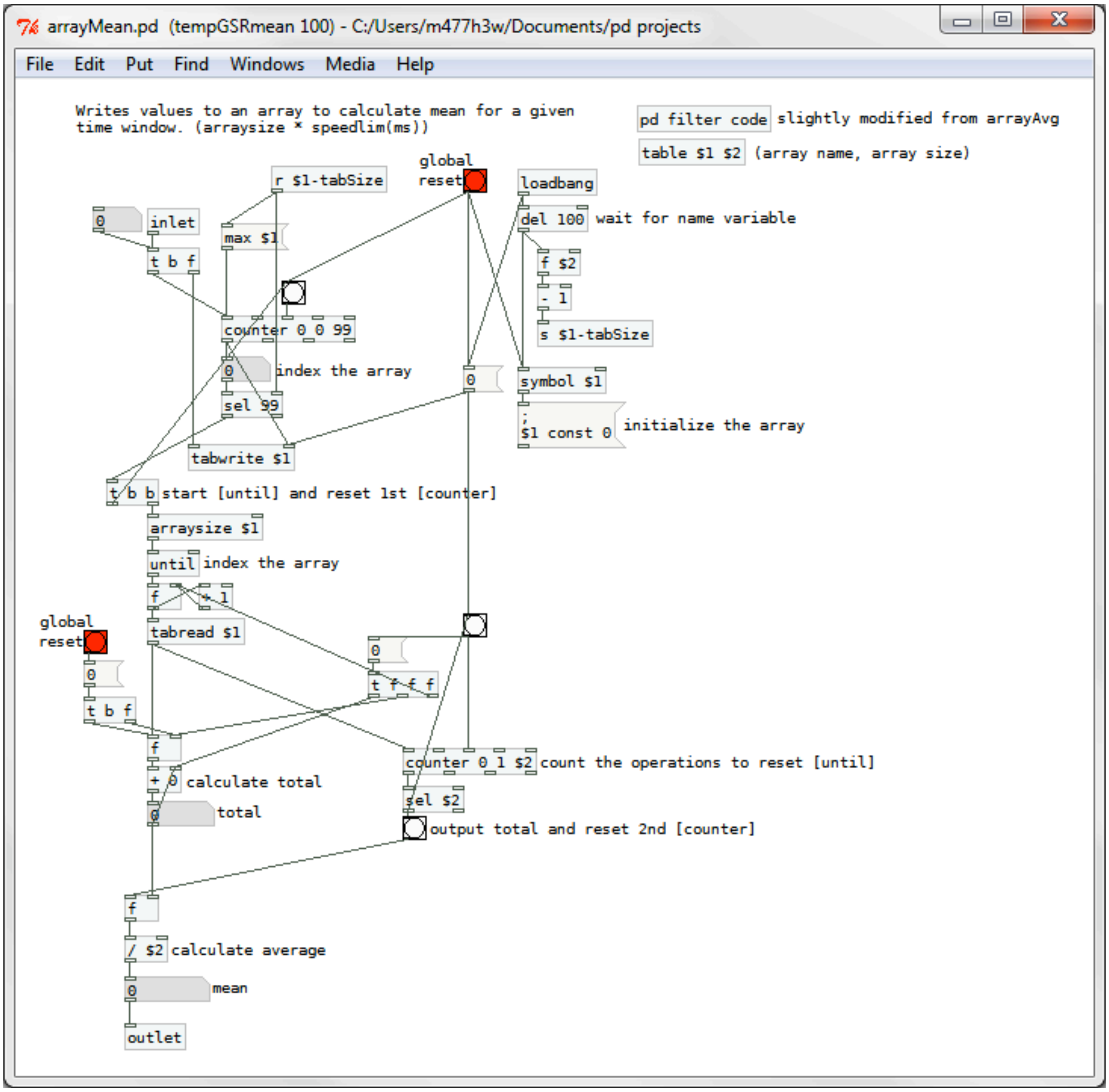

Figure 55: [arrayMean] writes data to an array for analysis

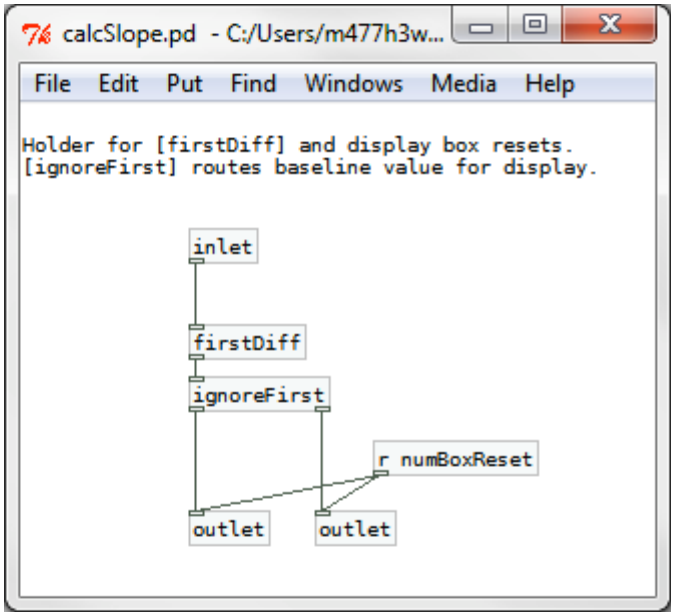

Figure 56: [calcSlope] routes slope values for display and analysis

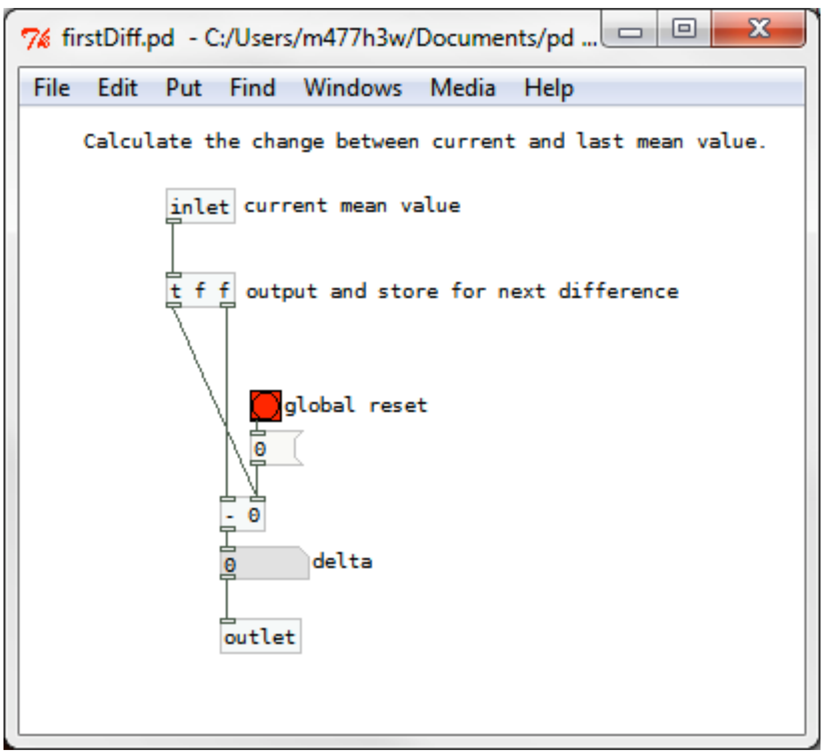

Figure 57: [firstDiff] calculates the running slope of a data stream

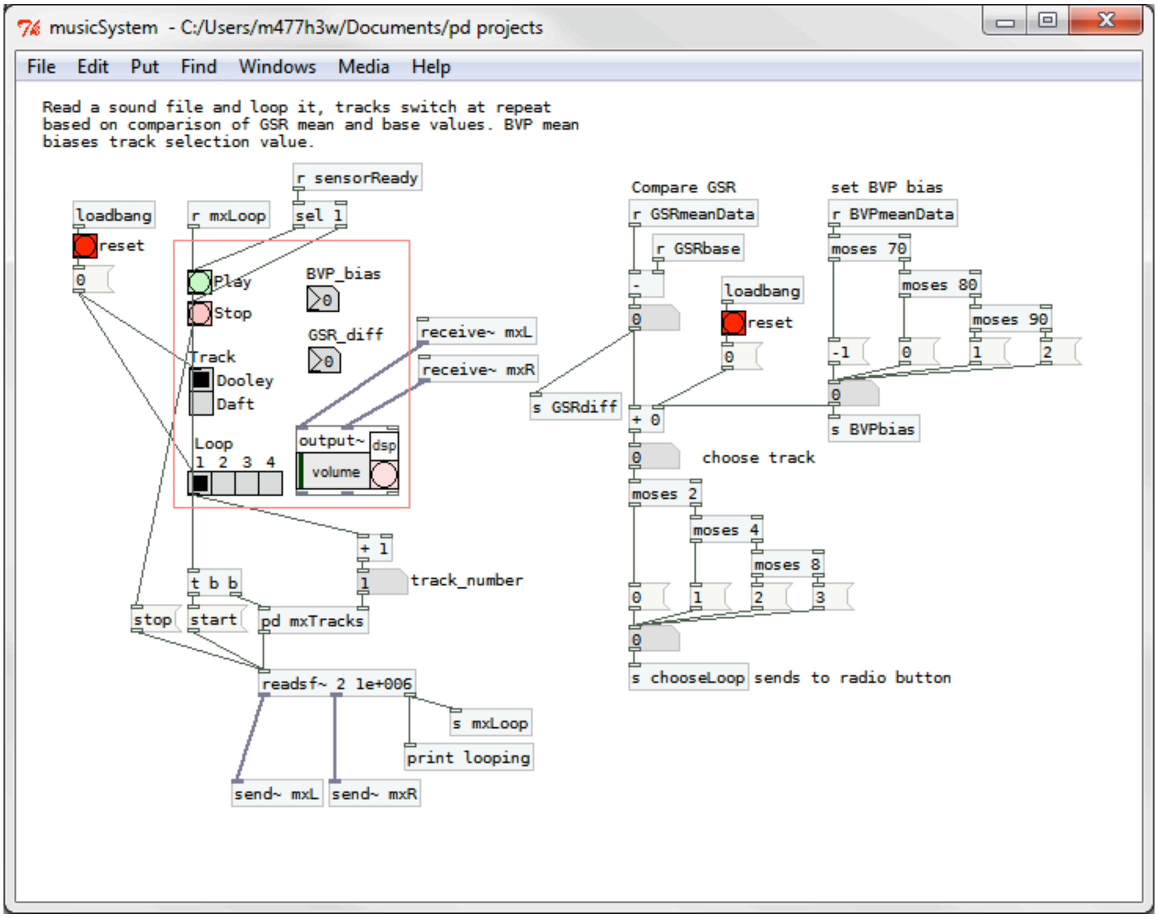

Figure 58: [musicSystem] graphical user interface of the music system with data processing algorithm for music control

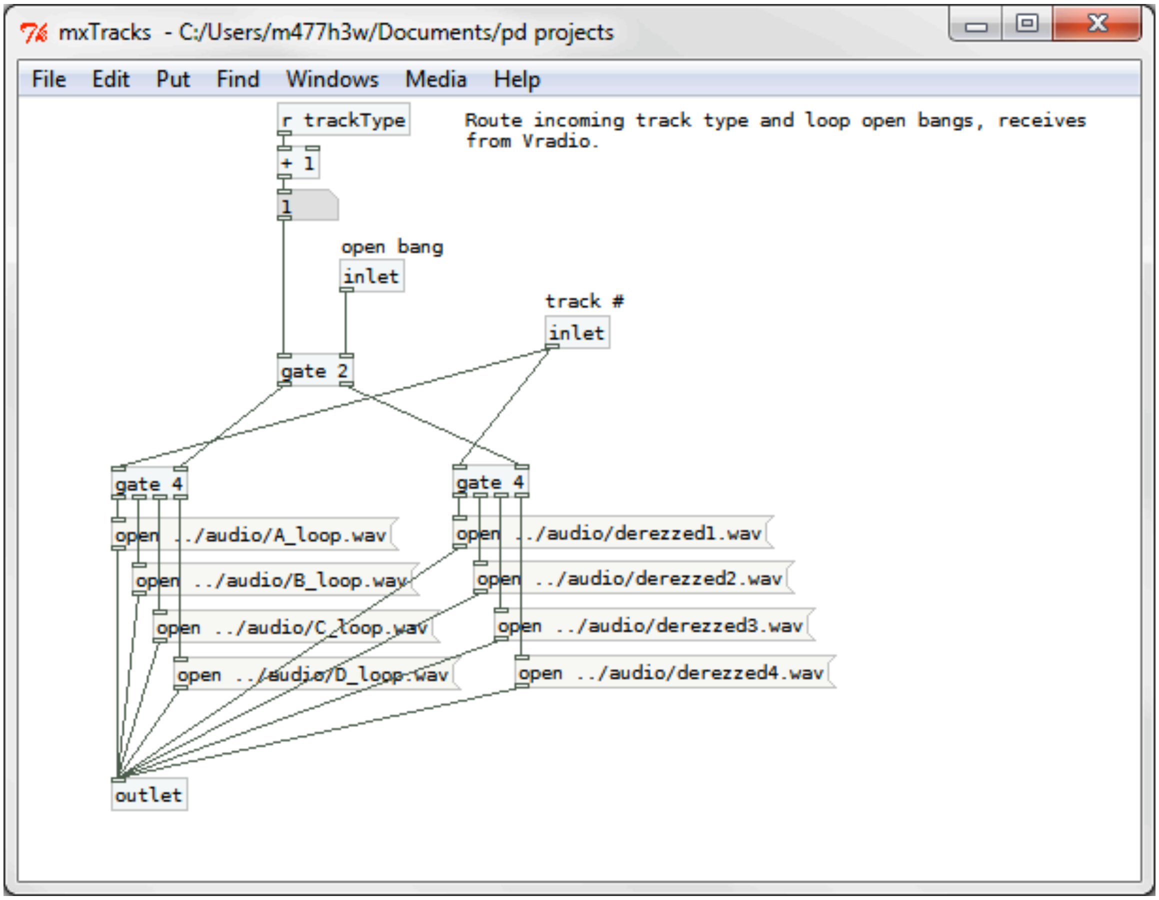

Figure 59: [mxTracks] selects the proper music loop depending on user selection

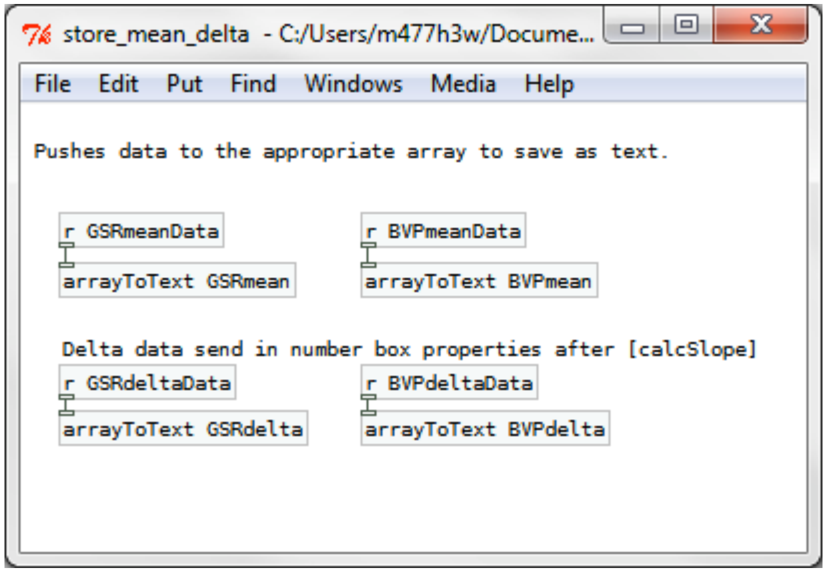

Figure 60: [store_mean_delta] routing analysis data for storage

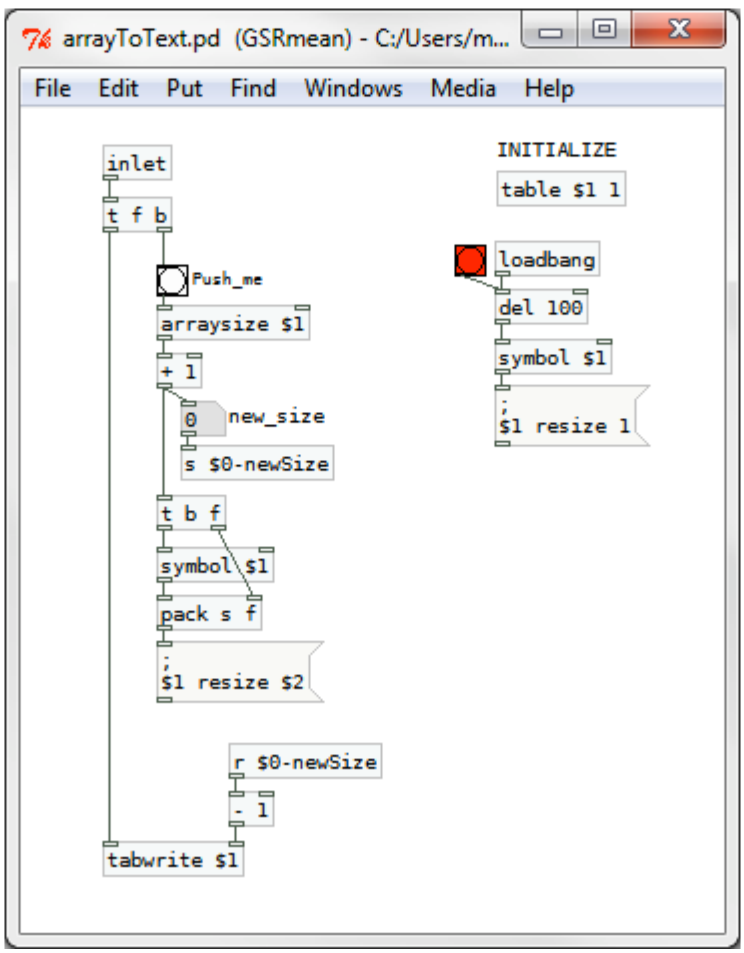

Figure 61: [arrayToText] writes analysis data to appropriate array

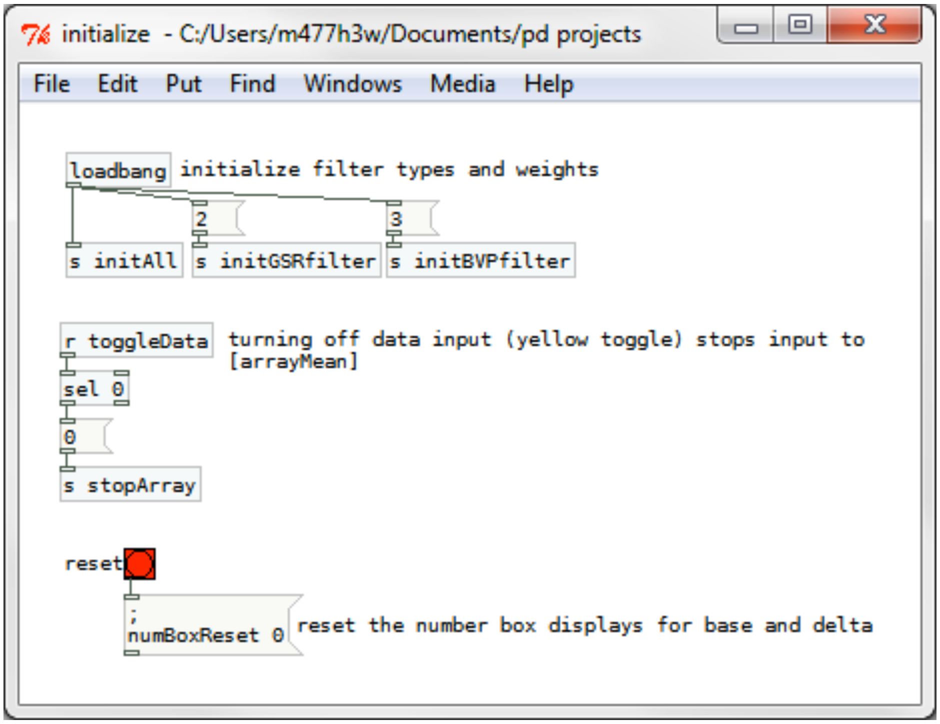

Figure 62: [initialize] initialization subpatch

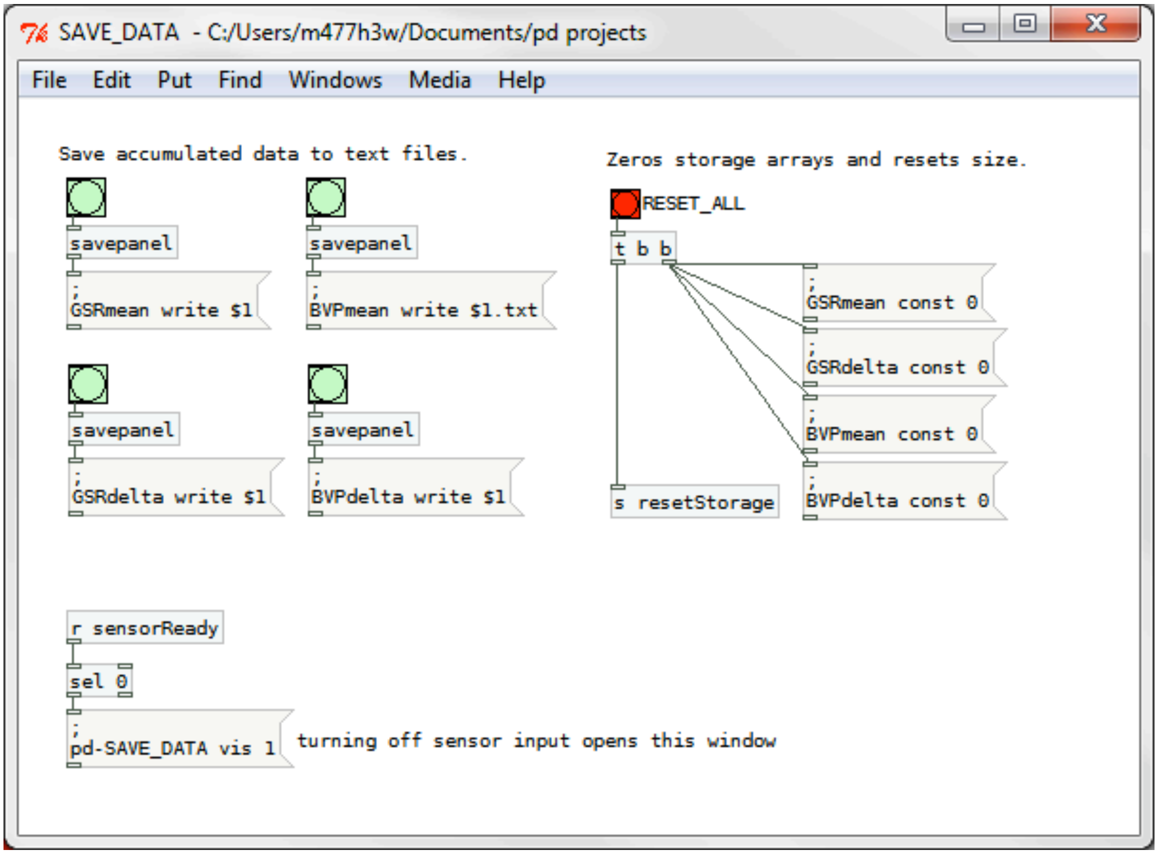

Figure 63: graphical user interface for storing analysis data to text files

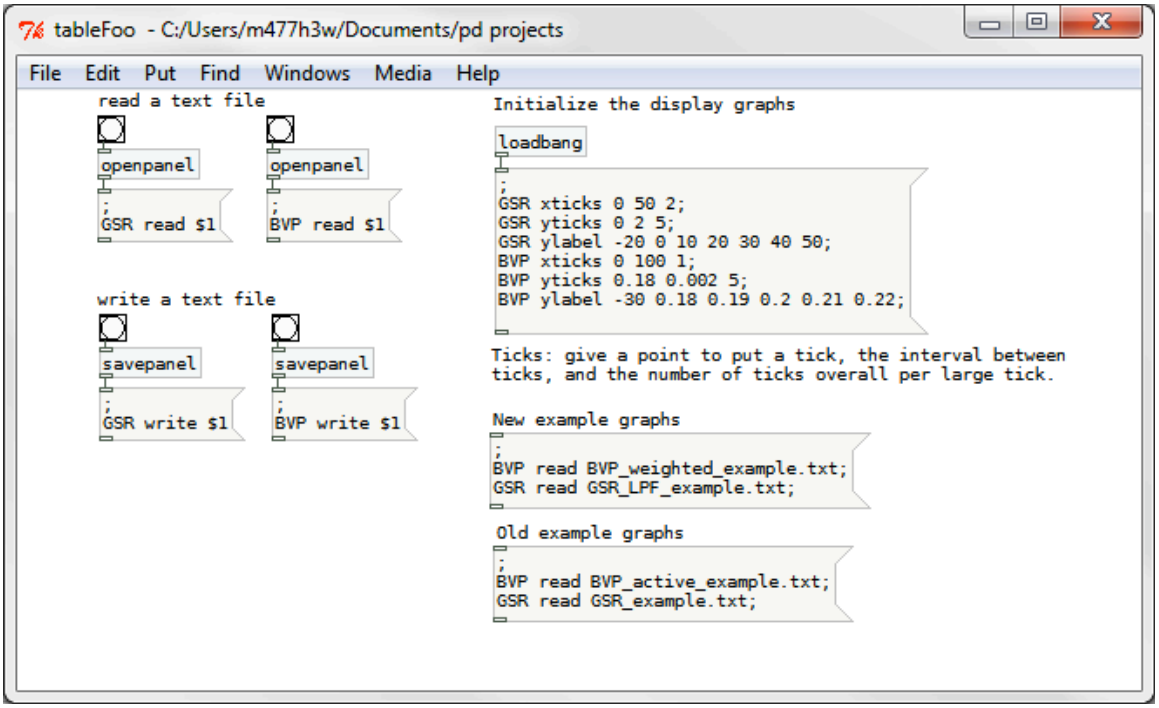

Figure 64: [tableFoo] graphical user interface for manipulating the graph displays

Appendix D: Biosignal Statistics

	F-Zero GX		Gradius ReBirth	
	Mean	SD	Mean	SD
Test 1	28.718	0.871	28.113	2.160
Test 2	17.136	1.399	26.701	1.734
Test 3	29.772	1.348	40.335	1.815
Total	25.046	5.748	29.629	4.907

	Prince of Persia		Tetris Worlds	
	Mean	SD	Mean	SD
Test 1	18.208	1.023	21.123	2.574
Test 2	11.442	2.405	18.388	0.690
Test 3	37.328	3.479	15.926	1.272
Total	21.281	10.766	17.945	2.674

All Tests	
Mean	SD
22.769	7.881

Table 1: GSR play test data

	F-Zero GX		Gradius ReBirth	
	Mean	SD	Mean	SD
Test 1	62.607	3.801	60.354	3.637
Test 2	79.623	16.535	69.134	4.897
Test 3	70.383	3.558	75.991	1.663
Total	69.899	12.250	64.344	6.969

	Prince of Persia		Tetris Worlds	
	Mean	SD	Mean	SD
Test 1	57.306	3.209	73.695	2.624
Test 2	69.638	13.848	59.331	6.804
Test 3	78.535	5.323	69.727	11.696
Total	77.046	7.659	67.884	10.368

All Tests	
Mean	SD
74.094	9.560

Table 2: BVP play test data

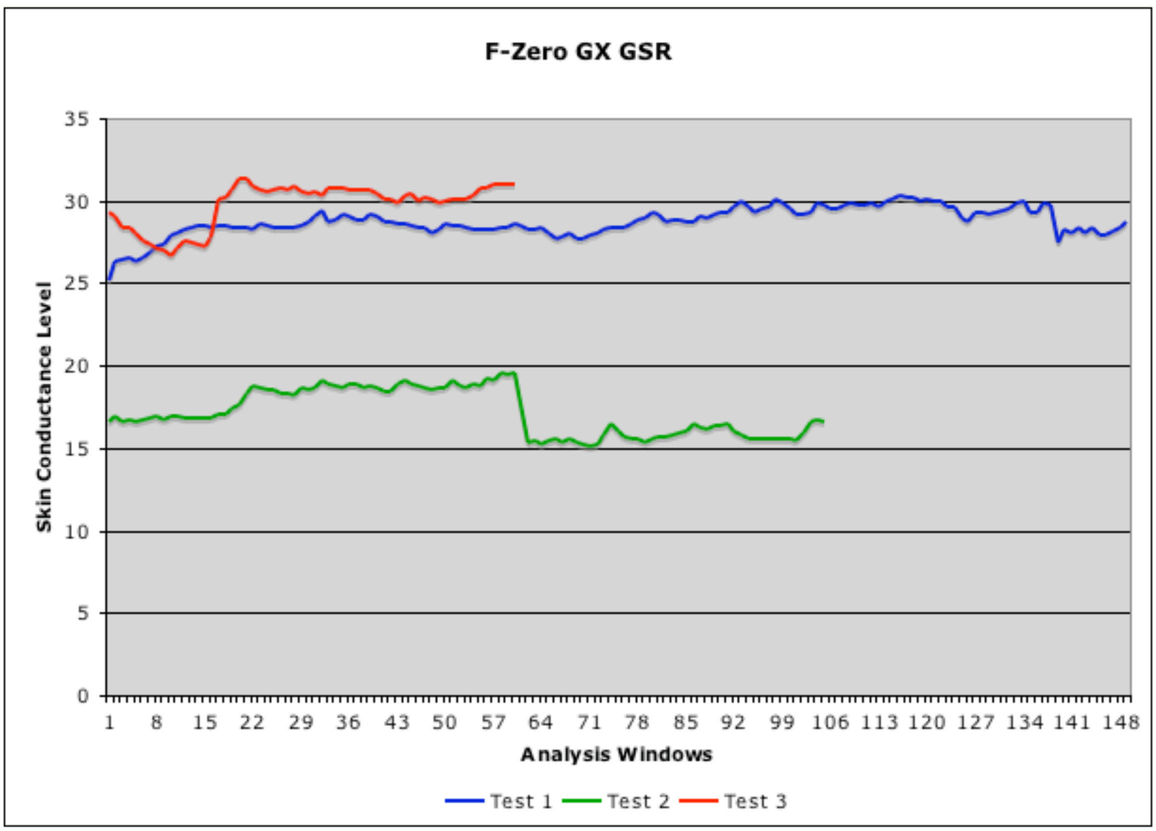

Figure 65: F-Zero GX GSR playtest signals

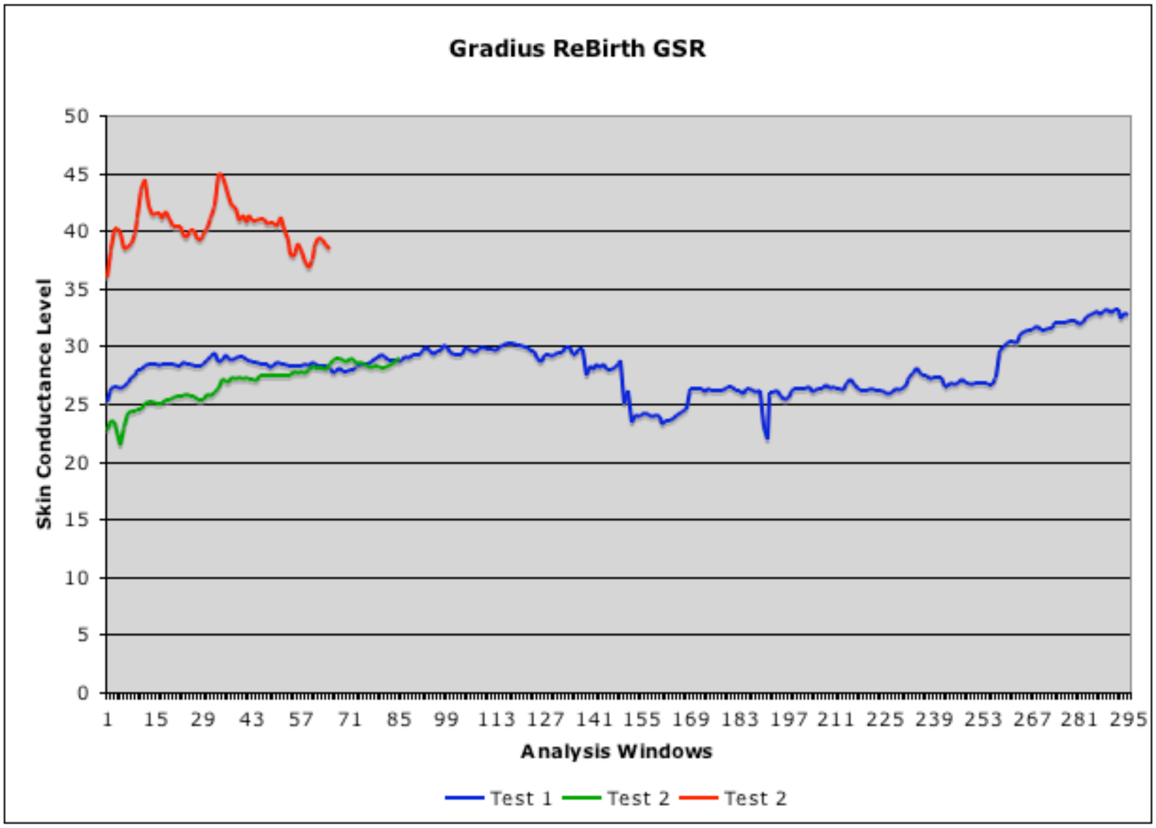

Figure 66: Gradius ReBirth GSR playtest signals

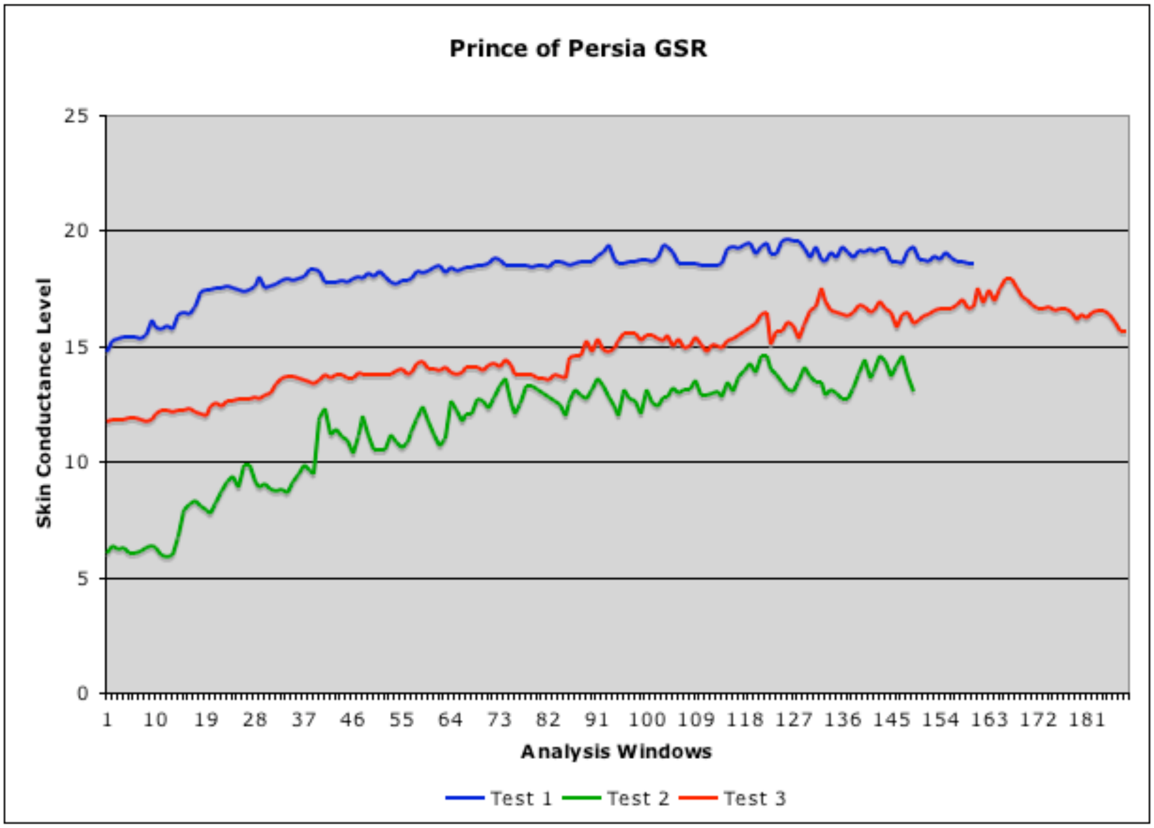

Figure 67: Prince of Persia GSR playtest signals

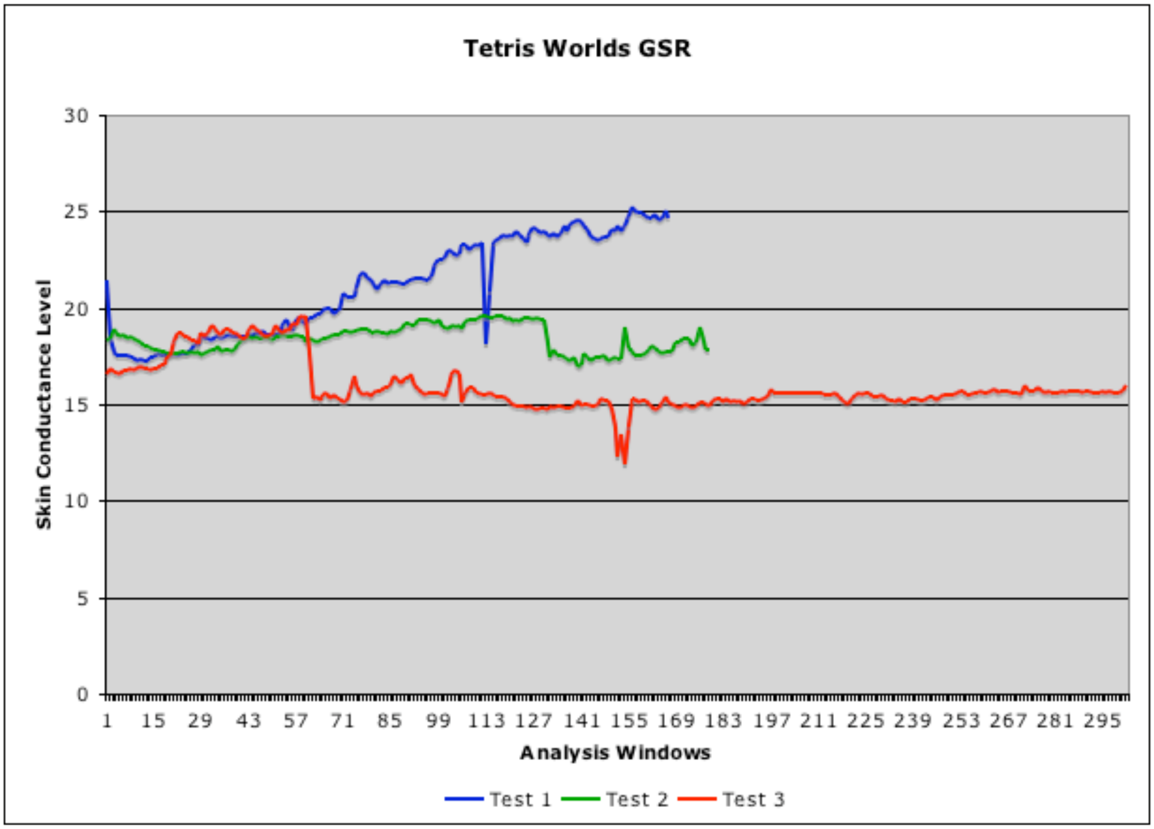

Figure 68: Tetris Worlds GSR playtest signals

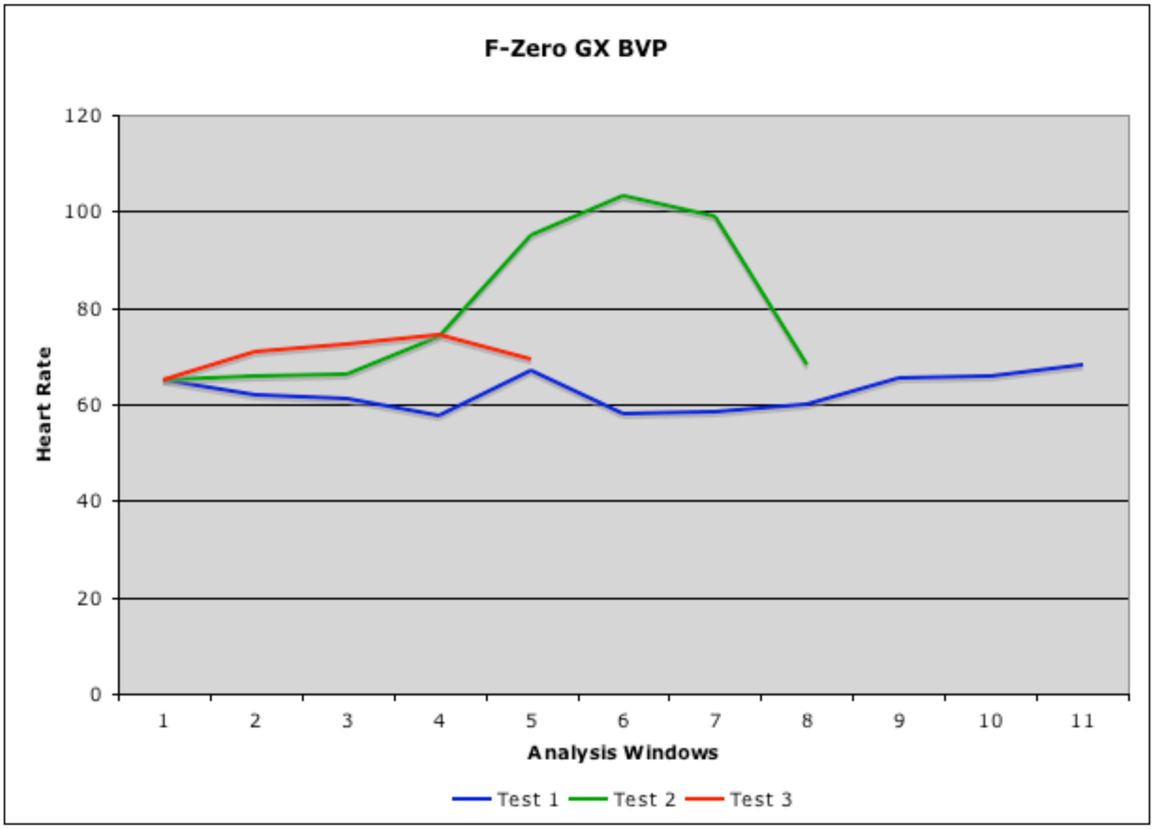

Figure 69: F-Zero GX BVP playtest signals

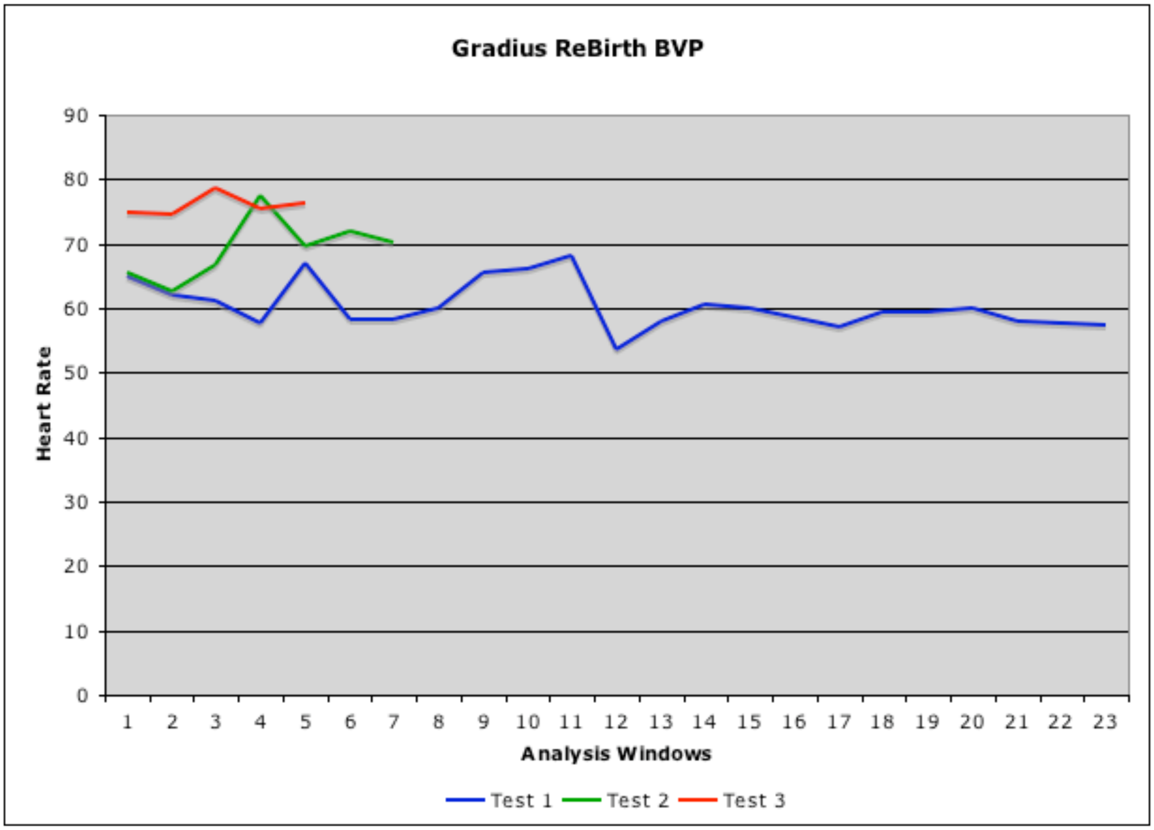

Figure 70: Gradius ReBirth BVP playtest signals

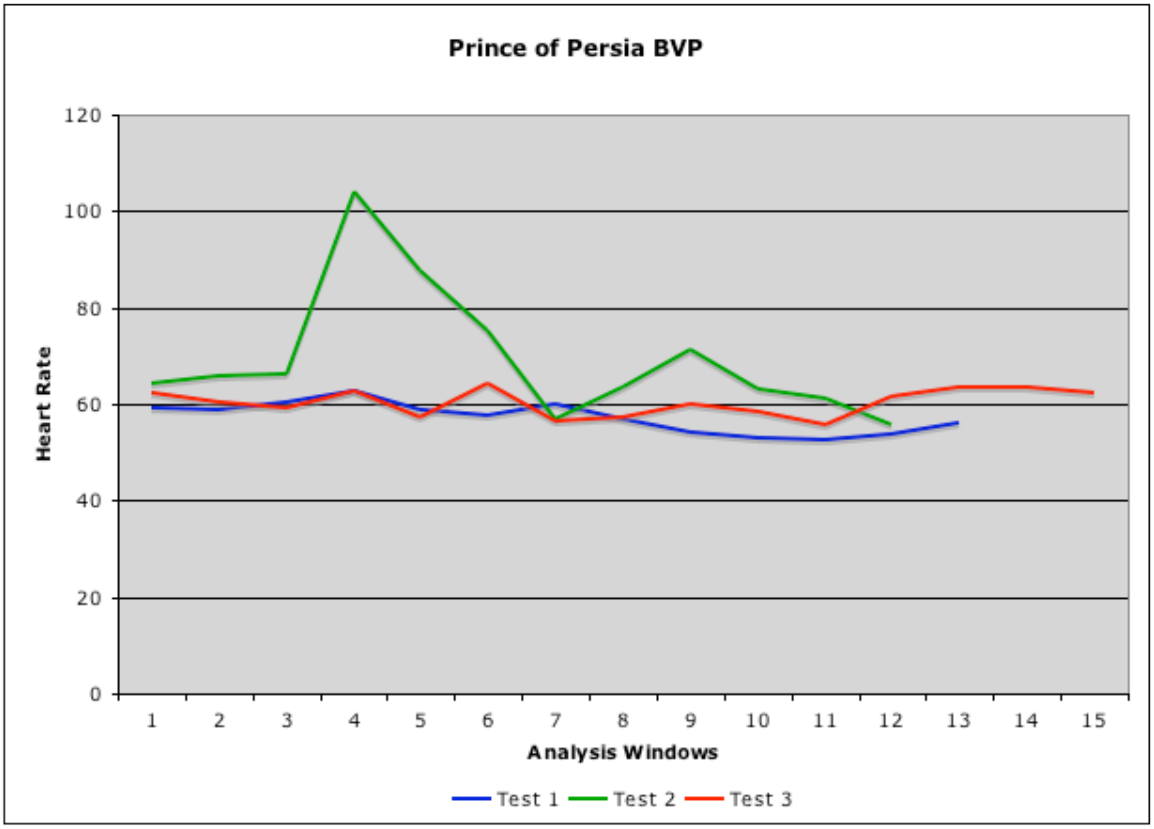

Figure 71: Prince of Persia BVP playtest signals

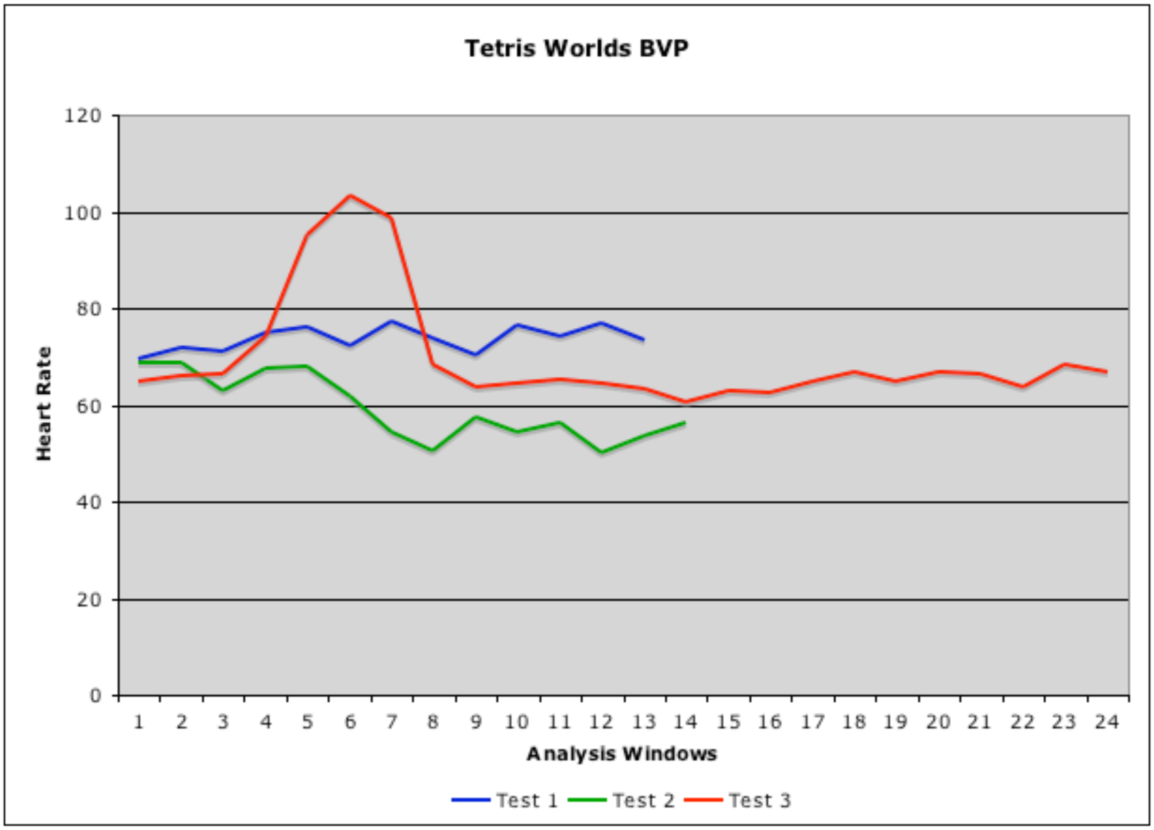

Figure 72: Tetris Worlds BVP playtest signals

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